LESSONS IN BOTANY

BY

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PREFACE.

THIS abbreviated and simplified edition of my Elementary Botany has been prepared for the use of pupils in the secondary schools, where short, or half-year, courses in botany are given, and where, for one reason or another, my larger book cannot be adapted to such abbreviated courses. A large part of the matter has been rewritten, only the less technical descriptive portions being retained.

The subject-matter is arranged for three different uses: exercises for the pupils, demonstrations by the teacher, and descriptive matter for reading and reference. To clearly set apart, for the convenience of the teacher and pupil, the work suggested for each, all the work outlined for the teacher is placed under the head of *demonstration*, whether the setting up of apparatus or an actual demonstration before the class; so also all the practical work of the pupils, whether an experiment or an ordinary exercise, is put under the head of *exercise*. The demonstrations and the exercises each have their own consecutive numbering, so that the teacher can tell at a glance the subdivisions of the work. Where there are a sufficient number of microscopes, so that one can be allotted to two or three pupils, many of the demonstrations can be used as exercises, at the discretion of the teacher. All the paragraphs, whether descriptive, demonstration or exercise, have a separate and consecutive numbering.

The first chapter in this abbreviated book is devoted to a study of how seedlings grow from the seed, and this is followed by a chapter on shoots, buds, etc., in order to give an opportunity for some out-door work if the season is propitious, or for

the study of material easily collected. This emphasizes the desirability of supplementing the regular laboratory course with the out-door work, or with observations on material suitable to be employed in out-door work when conditions permit. The third chapter then treats of protoplasm (the living substance) in the root hairs of seedlings, followed by a similar study in spirogyra. In the following chapters much the same order is used as in the larger book, but there has been an attempt to simplify the treatment. Very much of the technical matter in the larger book has been omitted here, and in consequence much of the matter which is useful for reference to those who desire supplementary reading and explanations. For this matter the larger Elementary Botany should be consulted.

The studies indicated in the part on ecology are not intended to be pursued as a distinct and separate piece of work, but they may be made the basis of excursions during the progress of the work on physiology and morphology. It is possible to indicate definitely where some of these out-door studies are applicable. At the same time the retention of the third part as a distinct subdivision of the book serves to emphasize the importance of ecological study, or perhaps rather of the study of plant life on a larger scale, and some of the interesting problems connected with the environmental influences on plant life and plant communities. It should be recognized that plant distribution, as well as many of the other important problems connected with ecological study, cannot be carried on in the secondary schools with the rigid system applicable in the college or university, or even with the precision which the student of ecology would desire, since a considerable previous technical knowledge of plants would be necessary. The chief importance of the study in the secondary schools is, I believe, to get the pupil interested in observing living plants, and in gaining a general impression of the fundamental laws, and in leading the pupil to realize, in a measure, the great influence which environment has on living beings.

It is suggested that the teacher, at the beginning of the work, take some account of the time to be allotted to the different subjects of the course. For example, in a 20-weeks' course, 7 to 8 weeks could be devoted to physiology, 5 or 6 weeks could be devoted to general morphology; while 6 or 8 weeks could be devoted to the study of plant families. As the work progresses it can be easily seen whether or not all the exercises and demonstrations can be gotten in during the allotted time. If the time is too short in some cases, the teacher can then arrange to omit certain of the exercises in each chapter, so that as a whole the work can be completed in the desired time. Some of the chapters are intended for reading and reference only. These are indicated at the beginning of the chapters in question. They should not be taken into account when considering the amount of practical work to be done by the pupil.

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PART I. PHYSIOLOGY.

CHAPTER I.

HOW THE SEEDLING GROWS FROM THE SEED.

1. Since the seedling plant is useful in illustrating several of the life processes of plants we may well begin with some studies of germinating seeds. We may take for the first example the pumpkin seedling, and then follow with several others in order to become familiar with the parts of the seedling plant before we study the life processes.

THE PUMPKIN SEEDLING.

Demonstration I.

2. To prepare seeds for germination.—Soak a handful of seeds (or more if the class is large) in water for twelve to twenty-four hours. Take shallow crockery plates, or ordinary plates, or a germinator with a fluted bottom. Place in the bottom some sheets of paper, and if sphagnum moss is at hand scatter some over the paper. If the moss is not at hand, throw the upper layer of paper into numerous folds. Thoroughly wet the paper and moss, but do not have an excess of water. Scatter the seeds among the moss or the folds of the paper. Cover with some more wet paper and [illegible] in a room where the temperature is about 20° C. to 25° C. The germinator should be looked after to see that the paper does not become dry. It may be necessary to cover it with another vessel to prevent the too rapid evaporation of the water. The germinator should be started about a week before the seedlings are wanted for study. Some of the soaked seeds should be planted in soil in pots and kept at the same temperature, for comparison with those grown in the germinator.

3. Structure of the pumpkin seed.—The pumpkin seed has a tough papery outer covering for the protection of the embryo plant within. This covering is made up of the seed coats. When the seed is opened by slitting off these coats there is seen within the "meat" of the pumpkin seed. This is nothing more than the embryo plant. The larger part of this embryo consists of two flattened bodies which are more prominent than any other part of the plantlet at this time. These two flattened bodies are the two first leaves, usually called *cotyledons*. If we spread these cotyledons apart we see that they are connected at one end. Lying between them at this point of attachment is a small bud. This is the *plumule*. The plumule consists of the very young leaves at the end of the stem which will grow as the seed germinates. At the other end where the cotyledons are joined is a small projection, the young root, often termed the *radicle*.

4. How the embryo gets out of a pumpkin seed.—To see how the embryo gets out of the pumpkin seed we should examine seeds germinated in the folds of damp paper or on damp sphagnum, as well as some which have been germinated in earth. Seeds should be selected which represent several different stages of germination.

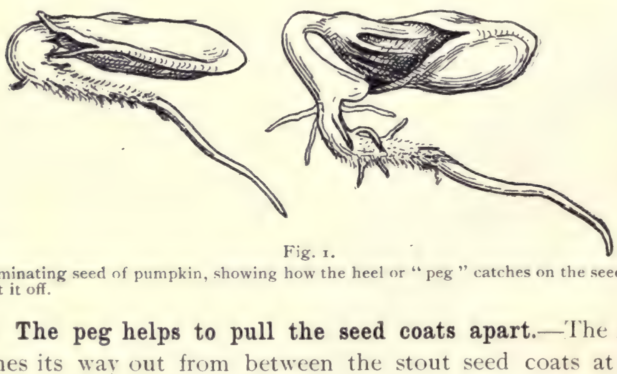

Fig. 1.

Germinating seed of pumpkin, showing how the heel or "peg" catches on the seed coat to cast it off.

5. The peg helps to pull the seed coats apart.—The root pushes its way out from between the stout seed coats at the smaller end, and then turns downward unless prevented from so

doing by a hard surface. After the root is 2–4*cm* long, and the two halves of the seed coats have begun to be pried apart, if we look in this rift at the junction of the root and stem, we shall see that one end of the seed coat is caught against a heel, or "peg," which has grown out from the stem for this purpose. Now if we examine one which is a little more advanced, we shall see this heel more distinctly, and also that the stem is arching out away from the seed coats. As the stem arches up its back in this way it pries with the cotyledons against the upper seed coat, but the lower seed coat is caught against this heel, and the two are pulled gradually apart. In this way the embryo plant pulls itself out from between the seed coats. In the case of seeds which are planted deeply in the soil we do not see this contrivance unless we dig down into the earth. The stem of the seedling arches through the soil, pulling the cotyledons up at one end. Then it straightens up, the green cotyledons part, and open out their inner faces to the sunlight, as shown in fig. 3. If we dig into the soil we shall see that this same heel is formed on the stem, and that the seed coats are cast off into the soil.

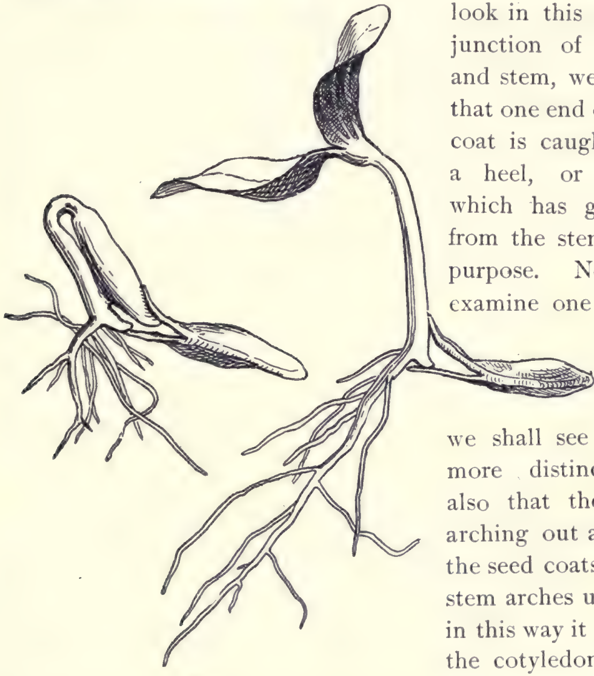

Fig. 2.
Escape of the pumpkin seedling from the seed coats.

6. Parts of the pumpkin seedling.—During the germination of the seed all parts of the embryo have enlarged. This increase in size of a plant is one of the peculiarities of growth. The cotyledons have elongated and expanded somewhat, though not to such a great extent as the root and the stem. The cotyledons also have become green on exposure to the light. Very soon after the main root has emerged from the seed coats, other lateral roots begin to form, so that the root soon becomes very much branched. The main root with its branches makes up the root system of the seedling. Between the expanded cotyledons is seen the plumule. This has enlarged somewhat, but not nearly so much as the root, or the part of the stem which extends below the cotyledons. This part of the stem, i.e., that part below the cotyledons and extending to the beginning of the root, is called in all seedlings the *hypocotyl*, which means "below the cotyledon."

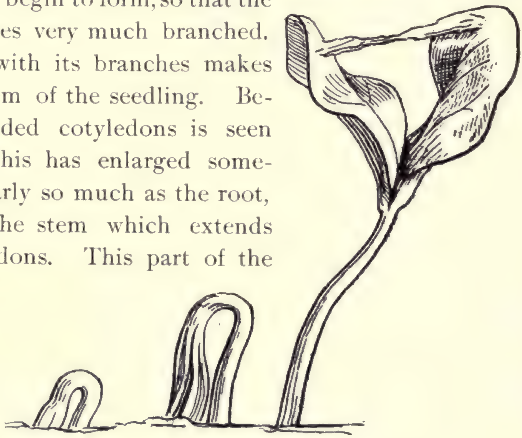

Fig. 3.
Pumpkin seedling rising from the ground.

Exercise 1.

7. Structure of a squash or pumpkin seed.—Sketch a squash or pumpkin seed, noting carefully the form and markings. Split off the tough papery seed coats (*testa*), from a seed which has been soaked in water, to observe the embryo. Note the large, flattened cotyledons. Spread them gently apart to see the attachment at the smaller ends, where they are attached to the short caulicle (stem). Sketch the embryo in this position showing the cotyledons, the plumule between them, and the short radicle projecting from the end where the cotyledons are attached; name the parts of the embryo. Make a cross-section of another seed through the middle, and observe the relation of the cotyledons to the seed coats; sketch. Make a cross-section

of a seed near the smaller end so that the section will cut across the plumule; sketch showing the positions of the different parts and the relation to the seed coats.

Exercise 2.

8. Structure of the bean seed.—Take beans which have been soaked in water. Sketch a bean, showing the form, the scar (*hilum*) on the concave side, the minute pit (*micropyle*) by the side of the hilum. Remove the testa (seed coats) from one of the beans; note the large thick cotyledons; determine where the cotyledons are joined (or attached to the young caulicle). Along one side of this point of attachment note the young radicle; at the other end between the cotyledons note the plumule.

Split open a bean along the line where the cotyledons meet; sketch one half, showing the young plumule and the venation of the leaf, and at the other side the young radicle. Make a cross-section of a bean and sketch to show the relation of the cotyledons to the seed coats, and the plumule between the cotyledons.

If there is time, compare a pea seed.

Exercise 3.

9. Structure of the grain of corn.—Take grains of corn that have been soaked. Note the form, and the difference of the two sides. Sketch a grain of corn showing the depressed area near the smaller end.

Make a longisection of a grain of corn through the middle line. (If necessary make several to obtain one which shows the structures well near the smaller end of the grain.) Sketch the section as shown by one half, observing the following structures: 1st, the hard outer "wall" (formed of the consolidated wall of the ovary with the integuments of the ovules—see Chapters 32 and 33); 2d, the greater mass of starch and other plant food (the endosperm) in the centre; 3d, a somewhat crescent-shaped body (the *scutellum*) lying next the endosperm and near the smaller end of the grain; 4th, the remaining portion of the young embryo lying between the scutellum and the seed coat in the depression. When good sections are made one can make out the radicle at the smaller end of the seed, and a few successive leaves (the plumule) which lie at the opposite end of the embryo shown by sharply curved parallel lines. Observe the attachment of the scutellum to the caulicle at the point of junction of the plumule and the radicle. The scutellum is a part of the embryo and represents a cotyledon.

Dissect out an embryo from another seed, and compare with that seen in the section.

Exercise 4.

10. The squash (or pumpkin) seedling.—Take seedlings in different stages of germination which have been grown in a germinator. Make sketches of several different stages, showing the expanded cotyledons, the plumule between them, the main root, and the origin of the lateral roots, the hypocotyl (the portion of the stem between the root and the cotyledons). Note the "peg" on the hypocotyl and determine the way in which this organ assists the embryo in getting out of the seed coats. Compare seedlings growing in the soil.

11. Other seedlings.—Make a similar study of the bean, pea, and corn seedlings, both from seeds germinated in folds of damp paper, and from those grown in the soil. Sketch the different stages, and write a full description and comparison, noting the points of agreement and disagreement between them, and the different ways in which the seedlings come up from the ground.

(Consult Chapter 33).

Material.—Seeds of the pumpkin or squash, beans, peas, and corn. These should be soaked in water for about twenty-four hours before they are wanted for the study of the seed.

Seedlings of the same plants in different stages of germination. Some of the seeds should be germinated in folds of wet paper or in moss, and some of them should be planted in soil in pots. These should be started about a week in advance of the time when they are wanted for study by the student. The number of seeds and seedlings which should be prepared will depend on the number of students in the class. A surplus of material should be provided for.

CHAPTER II.

WINTER BUDS, SHOOTS, ETC.

12. Season for study of shoots.—Either the autumn or the winter is an excellent time for some observations of the winter condition of plants, especially of the stems or shoots, as well as the leaves. While actual growth of the parts cannot then be observed, certain interesting and important peculiarities of the stems and leaves can then be easily studied. The exercises are also instructive for classes which have not had previous instruction in nature studies.

13. Annuals, biennials, perennials.—One of the striking things which we observe during the winter season is the fact that certain plants, especially the herbs, like many weeds and cultivated plants, are dead and dry. Where the plant makes its entire growth during the year or season, and ripens at the close, it is an *annual.* The bean, corn, squash, the ragweed, etc., are annuals. Other plants, like the thistle, mullein, etc., do not mature their fruit or seed until the second year. Such plants are *biennials.* Trees, shrubs, and many herbs as well, like the asters, goldenrods, etc., live from year to year, and are therefore *perennials.* In the goldenrods, in trillium, the toothwort, and other perennials of this kind, the larger part of the annual growth dies back at the close of the season, while the plant is carried over the winter by the shorter underground stem.

14. Annual growth of the horse-chestnut.—In figure 4 there is illustrated a shoot of the horse-chestnut. Near the middle portion of the shoot is a ring of numerous fine scars, and another ring of similar scars near the lower end. These rings of scars mark the positions of successive annual terminal buds,

Fig. 4
Two-year old twig of horse chestnut, showing buds and leaf scars. (A twig with a terminal bud should have been selected for this figure.)

so that the portion of the shoot between two such adjacent rings, or above the last one, represents the growth in length of the shoot for one year. At the close of the season's growth the "bud" is formed. In the horse-chestnut the terminal bud is broader than the diameter of the shoot, and is ovate in form.

15. We notice that there are a number of scales which overlap each other somewhat as shingles do on a roof, only they are turned in the opposite direction. If we begin at the base of the bud, we can see that the two lowest scales are opposite each other, and that the two next higher ones are also opposite each other, and set at right angles to the position of the lower pair. In the same manner successive pairs of scales alternate, so that the third, fifth, seventh, etc., are exactly over the first, and the fourth, sixth, etc., are exactly over the second. Aside from the fact that these brown scales fit closely together over the bud, we notice that they are covered with a sticky substance which helps to keep out the surface water. Thus a very complete armature is provided for the protection of the young leaves inside.

16. Leaf scars.—The number of leaves developed during one season's growth in length of the shoot can be determined by counting the broad whitish scars which are situated just below each pair of lateral buds. Near the margin of these scars in the horse-chestnut are seen prominent pits arranged in a row. These little pits in the leaf scar are formed by the breaking away of the fibro-vascular bundles (which run into the petiole of the leaf) as the leaf falls in the autumn.

17. Lateral buds.—The lateral buds, it is noticed, arise in the axils of the leaves. Each one of these by growth the next year, unless they remain dormant, will develop a shoot or branch. Just above the junction of the upper pair of branches we notice scars which run around the shoot in the form of slender rings, several quite close together. These are the scars of the bud scales of the previous year. By observing the location of these ring scars on the stem the age of the branch may be determined, as well as the growth in length each year. Small buds may be frequently seen arising in the axils of the bud scales, that is after the scales have fallen, so that four to ten small buds may be counted sometimes on these very narrow zones of the shoot.

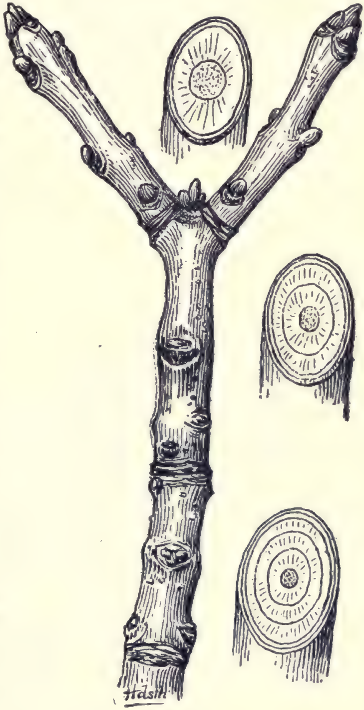

Fig. 5.

Three-year-old twig of the American ash, with sections of each year's growth showing annual rings.

18. Bud leaves.—On removing the brown scales of the bud there is seen a pair of thin membranous scales which are nearly colorless. Underneath these are young leaves; successive pairs lie farther in the bud, in outline similar to the mature leaves, and each pair smaller than the one just below it. They are very hairy, with long white woolly fibres. These woolly fibres serve also to protect the young leaves from the cold or from sudden changes in the temperature, since they hold the air in their meshes very securely.

19. Opening of the buds in the spring.—As the buds "swell" in the spring of the year, when the growth of the young leaves and of the shoot begins, the bud scales are thrown backward and soon fall away as the leaves unfold, thus leaving the "ring scar" which marks the start of the new year's growth in length of the shoot.

20. Variations in different shoots.—A study of a number of different kinds of woody shoots would serve to show us a series of very interesting variations in the color, surface markings, outline of the branch, arrangement of the leaves and consequently different modes of branching, variations in the leaf scars, the form, size, color, and armature of the buds, as well as great variations in the character of the bud scales. There are striking differences between the buds of different genera, and with careful study differences can also be seen in the members of a genus.

21. Growth in thickness of woody stems.—In the growth of woody perennial shoots, the shoot increases in length each year at the end. The shoot also increases in diameter each year, though portions of the shoot one year or more old do not increase in length. We can find where this growth in diameter of the stem takes place by making a thin cross-section of a young shoot or branch of one of the woody plants. If we take the white ash, for example, in a cross-section of a one-year-old shoot we observe the following zones: A central one of whitish tissue the cells of which have thin walls. This makes a cylindrical column of tissue through the shoot which we call the pith or medulla. Just outside of this pith is a ring of firmer tissue. The inner portion of this ring shows many woody vessels or ducts, and the outer portion smaller ducts, and a great many thick-walled woody cells or fibres. This then is a woody zone, or the zone of xylem.

The outer ring is made up of the bark, as we call it. In this part are the bast cells. Between the bark and the woody zone is a ring of small cells distinguished from the bark and the woody inner portion by the finer texture of the cut surface.

This is the growing cylindrical layer of the shoot which lies between the bark and wood throughout the extent of the shoot and in fact the entire tree. It is the *cambium*.

22. Annual rings in woody stems.—If we now cut across a shoot of the ash which is several years old, we shall note, as shown in fig. 5, that there are successive rings which have a similar appearance to the woody ring in the one-year-old stem. This can well be seen without any magnification. The larger size of the woody ducts which are developed each spring, and the preponderance of the fibres at the close of each season's growth, mark well the growth in diameter which takes place each year.

For further details consult Chapter XI, and also the author's larger "Elementary Botany."

23. Phyllotaxy, or arrangement of leaves.—In examining buds on the winter shoots of woody plants, we cannot fail to be impressed with some peculiarities in the arrangement of these members on the stem of the plant.

In the horse-chestnut, as we have already observed, the leaves are in pairs, each one of the pair standing opposite its partner, while the pair just below or above stand across the stem at right angles to the position of the former pair. In other cases (the common bed straw) the leaves are in whorls, that is, several stand at the same level on the axis, distributed around the stem. By far the larger number of plants have their leaves arranged alternately. A simple example of alternate leaves is presented by the elm, where the leaves stand successively on alternate sides of the stem, so that the distance from one leaf to the next, as one would measure around the stem, is exactly one half the distance around the stem. This arrangement is $\frac{1}{2}$, or the angle of divergence of one leaf from the next is $\frac{1}{2}$. In the case of the sedges the angle of divergence is less, that is $\frac{1}{3}$.

By far the larger number of those plants which have the alternate arrangement have the leaves set at an angle of divergence represented by the fraction $\frac{2}{5}$.

24. Other angles of divergence.—Other angles of divergence have been discovered, and much stress has been laid on what is termed a law in the growth of the stem with reference to the position which the leaves occupy. There are, however, numerous exceptions to this regular arrangement, which have caused some to question the importance of any theory like that of the "spiral theory" of growth propounded by Goethe and others of his time.

25. Adaptation in leaf arrangement.—As a result, however, of one arrangement or another we see a beautiful adaptation of the plant parts to environment, or the influence which environment, especially light, has had on the arrangement of the leaves and branches of the plant. Access to light and air are of the greatest importance to green plants, and one cannot fail to be profoundly impressed with the workings of the natural laws in obedience to which the great variety of plants have worked out this adaptation in manifold ways.

Exercise 5.

26. Shoots of the horse-chestnut.—Select shoots with strong terminal buds, and with several ring scars indicating several years' growth. Sketch a shoot, showing the ring scars, the leaf scars, the lateral and terminal buds, the lenticels (small rough elevations scattered over the surface of the twig, made up of corky tissue through which air is admitted). Note that the lateral buds arise in the axils of leaves (above the leaf scars). Are there buds in the axils of all the leaf scars on the shoot? How do they differ in size? Note that the larger and longer ones, from which the lateral branches usually arise, are usually situated near the terminal portion of each year's growth of the shoot. There was not room for all of the buds to grow into branches because they would be too crowded, and would shut out light and air. In the struggle for existence some have outgrown others which remain dormant ready to start growth if by accident the main shoot should be broken just above them.

Compare shoots which have borne flower-clusters for several years, and determine what effect this has had on the character of the branching.

27. Buds of the horse-chestnut.—Sketch in detail a large terminal bud. Note the color and texture of the outer scales of the bud. Is the texture of the outer bud scales such as to afford protection to the tender portion of the bud within? Is there any other means for protection of the buds?

Remove the scales one by one, determining the number, and their arrangement on the axis, as well as the difference in texture and form. Make a longitudinal section of the bud, and sketch one half to show the relation of the scales in the bud. Make a cross-section and sketch.

28. Annual growth in thickness as shown by the "annual rings."—With a sharp knife make cross-sections of the shoots of different ages, and from the number of annual rings determine the age of the shoot. Compare the annual rings with the number of ring scars on the shoot and see if the age of the shoot determined by both means is the same.

Exercise 6.

29. Comparative study of other shoots.—Study in a similar way other shoots, taking for example the walnut or butternut, the birch, elm, dogwood, peach, apple, etc. The selection may be made from trees or shrubs which are accessible, and for the purpose of illustrating several different types.

Sketch the form of the shoot, the position of the leaf scars, of the ring scars, of the buds, lenticels, etc.

Make careful notes upon these characters, as well as on the different colors, surface markings, etc.

Determine the age of the shoots, and of the branches, the relation of the dormant buds to those which have developed into the lateral shoots or branches. Determine the effect which fruit buds have had on the branching of the different species.

Make cross-sections and determine the age by the annual rings.

Exercise 7.

30. Comparative study of other buds.—Study the buds of several different shoots of trees and shrubs, for the purpose of determining the variations in the form of the bud scales, and the different means for the protection of the delicate scales within.

Examples suggested are as follows: walnut or butternut, hickory, currant, etc.

Sketch the form and surface characters of the buds, and note the color, or other characters.

Remove the scales one by one, note their arrangement on the shoot, their relation one to another in the bud. Determine the number of scales in a bud of the different kinds. Sketch the different forms of bud scales in each different kind of bud, arranging the sketches to represent the number of the scales, their form, and relative position on the axis, but far enough separated to show the details of each.

Exercise 8.

13. Comparison of leaf arrangement.—Study the arrangement of the leaves on several different shoots. by an examination of the leaf scars or by the buds. The teacher can select shoots which represent several different systems of phyllotaxy, for example the opposite and the alternate; among the alternate let the pupil determine those which have the angles of divergence represented by the fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, etc.

Exercise 9.

32. Field observations on trees and shoots.—If the weather is favorable an excursion to the woods, fields, or to some park or garden would be an appropriate conclusion to these exercises. The result can be made the basis of a short paper by each student. For example, let the pupil observe the habit (that is, the general form, character of branching, etc.) of different trees ; the character of the bark ; any further peculiarities of buds and shoots ; the differences between deciduous trees (those which shed all their leaves in the autumn, or whose leaves die), and evergreens. (In the evergreens the leaves remain green and attached to the trees for more than a year, for example in the pines for about three years. In this way while new leaves are formed each year, and old leaves are shed each year, there are green leaves on the tree at all seasons.)

Material (for exercises 5–8).—Shoots showing two or three years' growth of the following species (or others which may be more convenient in some localities) : horse-chestnut, birch, dogwood, apple, peach, etc., a selection to represent several different types. In selecting some of the shoots it will be well to collect some which have borne fruit and which have fruit buds, in order to compare the different type of branching induced on the fruit-bearing shoots. (If some of the material can be collected when the leaves are present and preserved, such leafy shoots will be interesting for comparison, especially shoots of the birch, which have short lateral branches bearing only two leaves each year.)

CHAPTER III.

THE LIVING SUBSTANCE OF PLANTS.

I. Protoplasm in Root Hairs of Seedlings.

33. Importance of studying protoplasm.—Now that we have become familiar with the parts of the seedling, have studied the germination of the seed, and have observed the increase in size and elongation of its parts we are impressed with the fact that it is a living thing. It is now time to inquire into the nature of the living substance of plants. Plant growth as well as some of the other life processes which we are about to study are at bottom dependent on this living matter. It is evident, then, that we should know something about it, how it appears, and how it acts. For with this knowledge it is easier to comprehend how the plant does its work as a living being. This living substance of plants is *protoplasm*. The student should now observe protoplasm in several plants. If there are not a sufficient number of microscopes to enable the students to make and study their own preparations, let the teacher prepare a demonstration for the members of the class.

Demonstration 2.

34. To prepare seedlings with clean root hairs.—Begin to prepare the seeds several days or a week before they are wanted for study. Soak a handful of corn or beans, radishes, etc. (or more if there is a large class) in an abundance of water for 24 hours. Prepare a moist chamber by placing a layer of moss (sphagnum) or cotton in the bottom of a wide vessel (a crockery plate or a germinator with a fluted bottom). Upon this place a layer of filter paper. Have the sphagnum and filter paper well wetted, but not with a sur-

plus of water. Remove the seeds from the water and scatter them over the paper. Place another sheet of wet filter paper over them, and if it is necessary, in order to keep the seeds moist, scatter among them a little damp absorbent cotton. Cover with a glass or with an inverted vessel to prevent too rapid evaporation of the moisture. Set aside in a warm place, about 22° C. to 25° C. (about 70°–80° Fahr.). Look at the culture every day to see that there is just the right amount of water to keep the seeds from drying, and also to see that there is not a surplus of water or the seeds will rot.

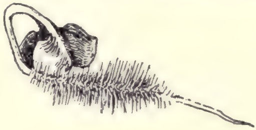

Fig. 6.
Seedling of radish, showing root hairs.

When the roots have begun to appear from the seeds remove the upper layer of paper and moss so that the root hairs can develop without interference. When the young roots just back of the tip are covered with a downy growth of colorless hairs, as in figure 6, they are ready for use.

Demonstration 3.

35. To prepare the root hairs for examination with the microscope.—Hold the root between the thumb and finger (or in this position between two thin pieces of elder pith to give it support). Then with a sharp razor, the blade resting on the forefinger and the edge against the root in the region of the root hairs, make a sliding cut across the root. Make several successive similar cuts in such a way as to get thin cross-sections of the root with the root hairs attached. Mount these sections in a drop of water on a glass slip and cover with a clean circle cover glass. Or with the needles tease out a small portion of the root with the root hairs attached. Tease apart the tissues in a drop of water, being careful not to break off the root hairs, and mount in water on a glass slip. Place the slip under the microscope and focus the microscope on suitable root hairs for demonstration of the protoplasm. Let each pupil be seated at the microscope for a few moments to observe the protoplasm in the root hairs.

Demonstration 4.

36. Protoplasm in the root hairs.—Examining this preparation with the aid of the microscope we see that each thread or root hair is a continuous tube. It is a single plant cell which has become very much elongated and free by pushing out its free end some distance from the other cells of the outer portion of the root. Observe the boundary wall of the thread. This is the *cell wall*. Within this the protoplasm is seen. It is colorless and very granular, that is, numerous small granules of different sizes lie quite closely together in a colorless slimy liquid. This is the protoplasm. It does not

entirely fill the root hair. But here and there are seen strands of this substance which cross the thread leaving clear spaces between. Or the clear spaces appear as rounded vacuoles of different sizes, or the vacuoles are more or less elongated. These clear spaces in the root hair are occupied by a watery substance known as the *cell sap*.

Fig. 7.
Root hairs of corn before and after treatment with 5% salt solution.

Demonstration 5.

37. Test for protoplasm.—Draw off the water from under the cover glass by the use of filter paper, and at the same time add some of the solution of iodine with a medicine dropper. Observe that the protoplasm is stained a yellowish-brown color. This is the reaction of protoplasm in the presence of iodine.

Exercise 10.

38. Study root hairs of seedlings.—Some of the seedlings prepared in demonstration 2 can be used by the members of the class for a study of the gross appearance of the root hairs.

Make a sketch of the seedling showing what portion of the root is covered by the root hairs. Why are not the root tips covered with the root hairs? Why are the root hairs absent from the older portions of the roots? As to strength and firmness how do the root hairs and roots compare? Test this by handling.

Immerse the portion of the root covered by the root hairs for a few moments in a solution of iodine. Do they take the stain? Will the stain all wash out in water when immersed for a few moments?

Take a fresh seedling with uninjured root hairs and immerse the root for a few moments in a 1% aqueous solution of eosin. Rinse in water. Do the root hairs hold the stain? Immerse the root for a few moments in strong alcohol, or in 2% formalin, and then immerse the root hairs in eosin. Rinse in water. Do the root hairs hold the stain now? Why?

Write out a complete account of your experiments and observations.

Synopsis.—The root hairs are formed near the growing end of the young root.

The root hair is a single plant cell, very long and narrow.

The root hair is formed by the elongation of one of the outer cells of the root.

The root-hair cell.
- Cell wall, the enclosing cellulose membrane to protect and hold the cell contents.
- Protoplasm.
  - Nucleus.
  - Granular protoplasm, arranged differently from that in spirogyra; a wall layer, and then stout strands and masses which reach across with clear rounded spaces between (the vacuoles).
  - Cell sap, in the vacuoles.
- Chlorophyll absent.

Reactions of the protoplasm; is killed, and stained yellowish brown with iodine; a 1% aqueous solution of eosin does not stain it; it does stain with the eosin when first killed with alcohol.

Materials.—Young seedlings of radish, corn, squash, or other plants, with clean root hairs, grown in a germinator (see Demonstration 2).

A solution of iodine.

A 1% aqueous solution of eosin.

95% alcohol (commercial strength).

Watch glasses to receive small quantities of these solutions when the pupils are engaged in exercise 10. Medicine droppers.

For the demonstrations: Microscope, razor, glass slips, cover-glass circles, dissecting needles. (Hereafter the microscope and accessories will not be listed in each case for the demonstrations; microscope, etc., will be inserted instead.)

CHAPTER IV.

THE LIVING SUBSTANCE OF PLANTS—CONTINUED.

II. PROTOPLASM IN AN ALGA: SPIROGYRA.

39. The plant spirogyra.*—There are a number of algæ which would serve the purpose quite as well as spirogyra, but we shall want to employ this plant again at a later time, and it is well now to become familiar with it. It is found in the water of pools, ditches, ponds, or in streams of slow-running water. It is green in color, and occurs in loose mats, usually floating near the surface. The name "pond scum" is sometimes given to this plant, along with others which are more or less closely related. If we lift a portion of it from the water, we see that the mat is made up of a great tangle of green silky threads. Each one of these threads is a plant, so that the number contained in one of these floating mats is very great.

Demonstration 6.

40. To prepare spirogyra for study under the microscope.—Lift up a bit of this thread tangle with a needle and place it in a drop of water on a "glass slip." With the needles tease apart the threads so that they will be scattered in the water. Now place over these threads in the water a clean, thin, glass circle. Place the preparation on the stage of the microscope and adjust for observation of a thread. Let the pupils first examine the plant under the low power of the microscope, and then under the high power. They should

* If spirogyra is in fruit some of the threads will be lying parallel in pairs, and connected by short tubes. In some of the cells may be found rounded or oval bodies known as *zygospores*. These may be seen in figure 93 and will be described in another part of the book.

first observe certain things about the plant enumerated in paragraphs 41 and 42, so that they will be able to tell it from other minute green algæ. When these things have been observed the protoplasm can be demonstrated. At one sitting each pupil can observe the things called for in paragraphs 41–44; make sketches and notes.

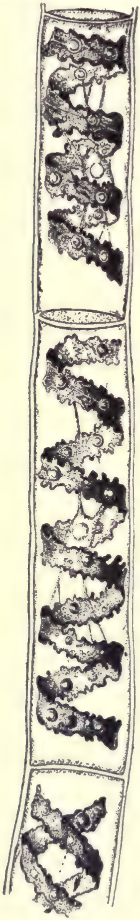

Fig. 8. Thread of spirogyra, showing long cells, chlorophyll band, nucleus, strands of protoplasm, and the granular wall layer of protoplasm.

41. Chlorophyll bands in spirogyra.—We first observe the presence of bands, green in color, the edges of which are usually very irregularly notched. These bands course along in a spiral manner near the surface of the thread. There may be one or several of these spirals, according to the species which we happen to select for study. This green coloring matter of the band is *chlorophyll*, and this substance, which also occurs in the higher green plants, will be considered in a later chapter. At quite regular intervals in the chlorophyll band are small starch grains, grouped in a rounded mass.

42. The spirogyra thread consists of cylindrical cells end to end.—Another thing which attracts our attention, as we examine a thread of spirogyra under the microscope, is that the thread is made up of cylindrical segments or compartments placed end to end. We can see a distinct separating line between the ends. Each one of these segments or compartments of the thread is a *cell*, and the boundary wall is in the form of a cylinder with closed ends.

43. Protoplasm.—Having distinguished these parts of the plant we can look for the protoplasm. It occurs within the cells. It is colorless (i.e., hyaline) and consequently requires close observation. Near the centre of the cell can be seen a rather dense granular body of an elliptical or irregular form, with its long diameter transverse to

the axis of the cell in some species; or triangular, or quadrate in others. This is the *nucleus*. Around the nucleus is a granular layer from which delicate threads of a shiny granular substance radiate in a star-like manner, and terminate in the chlorophyll band by one of the groups of starch grains. A granular layer of the same substance lines the inside of the cell wall, and can be seen through the microscope if it is properly focussed. This granular substance in the cell is *protoplasm*.

44. Cell-sap in spirogyra.—The greater part of the interior space of the cell, that between the radiating strands of protoplasm, is occupied by a watery fluid, the "cell-sap."

Demonstration 7.

45. Test for protoplasm in spirogyra.—Mount a few threads of spirogyra in a drop of weak solution of iodine for microscopic examination.

Fig. 9.
Cell of spirogyra before treatment with iodine.

Fig. 10.
Cell of spirogyra after treatment with iodine.

The iodine gives a yellowish-brown color to the protoplasm, and it can be more distinctly seen. The nucleus is also much more prominent since it colors deeply, and we can perceive within the nucleus one small rounded body, sometimes more,

the *nucleolus.* The iodine here has killed and stained the protoplasm.

46. Living protoplasm resists the action of some reagents.—If a few living threads are placed in a 1% aqueous solution of eosin, and after a time washed, the protoplasm remains uncolored. This teaches that protoplasm in a living condition resists for a time the action of some reagents. (The iodine and eosin here used are called reagents.) But let us place these threads for a short time, two or three minutes, in strong alcohol, which kills the protoplasm. Then mount them in the eosin solution. The protoplasm now takes the eosin stain. After the protoplasm has been killed the nucleus is no longer elliptical or angular in outline, but is rounded. The strands of protoplasm are no longer in tension as they were when alive.

Exercise 11.

47. The alga spirogyra.—Place some of the threads in a shallow vessel of water. Note the appearance of the threads, their length. Determine if branches are present or not. If a small hand lens is convenient, spread some of the threads out between two glass slips, and holding the preparation toward a lighted window look at it through the lens. Describe what is seen. Lift some of the threads with the aid of a needle, and notice how long and delicate they are. Feel of some between the thumb and finger. Pinch some of the threads and again place them in the water. Write an account of the observations.

Place some threads in a small quantity of alcohol and let remain for several minutes. Does the alcohol become colored green? Why?

Place some of the threads in a solution of iodine for a few moments. Rinse them in water. Do the threads hold the color? What is the color?

Place some fresh threads in a 1% solution of eosin for a few moments. Rinse in water. Do the threads hold the stain? Why? Place the same threads for a few moments in strong alcohol, and then in the eosin. Rinse in water. Do the threads now hold the color? Why?

Write out a complete account of your experiments and observations in this study of the gross characters of the plant spirogyra.

Synopsis.—The spirogyra plant occurs in quiet water.

Spirogyra cell.
- A single cell, cylindrical, is a section of a long thread.
- Cell wall of cellulose.
- Chlorophyll band, flattened, coiled spirally around the inner side of the wall, colored green by the chlorophyll substance.
- Protoplasm.
  - Nucleus, granular, near centre of cell.
  - Small nucleolus within nucleus.
  - Protoplasm proper (cytoplasm) radiating in strands from the nucleus; thin wall layer next the cell wall.
  - Cell-sap (watery substance) occupying the spaces between the strands of protoplasm.
- (Starch masses in the chlorophyll band.)

The spirogyra thread is made up of many of these cells lying end to end.

Reactions of protoplasm in spirogyra:

Stains yellowish brown with iodine.

A 1% aqueous solution of eosin does not stain the living protoplasm.

Alcohol kills the protoplasm, so that eosin will then stain it.

Materials.—Fresh mats of the pond-scum spirogyra, either freshly collected from ponds or ditches, or from an aquarium where it may be kept for a week or more in a fresh condition.

A solution of iodine.

A 1% aqueous solution of eosin.

95% alcohol.

Watch glasses for receiving the solutions when the pupils are engaged in exercises 11. Microscope, etc.

CHAPTER V.

THE LIVING SUBSTANCE OF PLANTS—CONCLUDED.

III. PROTOPLASM IN A FUNGUS: MUCOR.

NOTE.—Omit or read this chapter, or where there is time, if the teacher so desires, it may be studied in addition to spirogyra, or as an alternate if spirogyra cannot be obtained.

Demonstration 8.

48. To obtain the black mould.—If stock cultures of the black mould are not at hand it is well for the teacher to make some preparation several weeks beforehand for securing the mould for the cultures.

To do this take an orange or lemon, cut in halves, and squeeze out the juice. Let it lie exposed in the room for a day. Then place this with some old bread in a moist chamber and set aside in a warm room for several days. In this time several moulds will appear. Some may have a blue color, others white, and some will probably become black. The black one is quite likely to be the black mould. New cultures of the black mould should now be made on fresh bread, or on the cut surface of baked potatoes. If they are made on potatoes the following method will answer; if on bread put the pieces in a moist chamber and sow the spores as described here for the potato cultures.

Demonstration 9.

49. To make cultures of the black mould.—Take some freshly baked potatoes. Make a cut about 1*cm* deep entirely around them. Break them into halves and place these in moist chambers on damp paper with the cut surfaces uppermost. If a platinum needle which can be flamed is not at hand, take a dissecting needle, thrust it for a moment into strong alcohol. Hold it in the air until it is dry. Touch the moist surface of the potato with the needle, then touch the black heads of the fungus on the bread or fruit to catch some of the spores. Then touch the potato surface again, repeating this several times until spores have been put in a number of spots. Close the moist

chamber and set aside in a warm place. For several days observe the growth. First there appear small spots of delicate white threads. This tuft of threads increases in size, the threads elongate and branch.

Demonstration 10.

50. To prepare the mycelium of the black mould for study of the protoplasm.—These white threads of the mould are fungus threads. They are called the *mycelium*. The mycelium is the vegetative or growing portion of the mould, while the black heads are the fruiting portion. With a needle carefully lift a small tuft of these threads grown in the moist chamber, place them in a drop of water on the glass slip and carefully tease them apart so that individual threads can be seen. Prepare for study under the microscope. When the microscope has been focussed on a suitable group of threads each pupil can then observe the things noted in paragraphs 51–53.

51. Mycelium of the black mould.—Under the microscope we see only a small portion of the branched threads. There is no chlorophyll as in spirogyra. This is one of the important characters of the group of plants to which the black mould belongs. In addition to the absence of chlorophyll, we see that the mycelium is not divided at short intervals into cells, but appears like a delicate tube with branches, which become successively smaller toward the ends.

Fig. 11.
Thread of mucor, showing protoplasm and vacuoles.

52. Appearance of the protoplasm.—Within the tube-like thread now note the protoplasm. It has the same general appearance as that which we noted in spirogyra. It is slimy, or semi-fluid, partly hyaline, and partly granular, the granules consisting of minute particles (the *microsomes*). While in

mucor the protoplasm has the same general appearance as in spirogyra, its arrangement is very different. In the first place it is plainly continuous throughout the tube. We do not see the prominent radiations of strands around a large nucleus, but still the protoplasm does not fill the interior of the threads. Here and there are rounded clear spaces termed *vacuoles*, which are filled with the watery fluid, cell-sap. The nuclei in mucor are very minute, and cannot be seen except after careful treatment with special reagents.

53. Movement of the protoplasm in mucor.—While examining the protoplasm in mucor we are likely to note streaming movements. Often a current is seen flowing slowly down one side of the thread, and another flowing back on the other side, or it may all stream along in the same direction.

Exercise 12.

54. Study of mycelium.—Use portions of the mould which have not become black. These portions are the mycelium, mats of the fine colorless threads.

Note the color of the threads, the absence of chlorophyll. To test this place some of the threads in strong alcohol, let stand for some time. Does the alcohol become colored?

Take some fresh threads and place them in the iodine solution. Remove and rinse in water. What is the color?

Place fresh threads in some of the 1% aqueous solution of eosin, and rinse in water. Do the threads hold the color? Now immerse the same threads in strong alcohol, then rinse in water, and place in the eosin solution for a moment. Rinse in water. Do the threads now hold the stain? Why?

Write out a complete account of the experiments and observations.

Exercise 13.

55. To obtain the mould from fruits.—This may be made a home exercise if preferred. It is well whenever possible to get the pupils to do some of the work of preparation.

Let each pupil take half an orange or lemon, squeeze out the juice, and leave it exposed in his living room through the day. At night place it along with some pieces of bread in a glass tumbler, first putting a wet piece of paper in the bottom of the tumbler. Cover the vessel with a piece of glass. Keep in a warm room. Each day observe what appears, keeping notes, and describing the appearance of the mycelium. Observe if the black mould appears when the growth comes to fruit.

56. Protoplasm occurs in the living parts of all plants.—The substance we have found in the alga spirogyra, in the root hairs of the corn seedling, in the threads of the black mould, is essentially alike in all. It may be arranged differently in the different plants, but its general appearance is the same. It moves quite rapidly in the cells of some plants, but so slowly in others that we may not see the movement. Yet when we treat the protoplasm with well-known reagents the reaction in general is the same. It has been found by the experience of different investigators that the substance in plants which shows these reactions under given conditions is protoplasm. We have demonstrated to our satisfaction then that we have seen protoplasm in the simple alga spirogyra, in the root hairs of the seedling, and in the threads of the black mould. If we chose to make sections of the stems and leaves of the seedling, or of the living parts of other higher plants, we should find that protoplasm is present in all these living cells. We then conclude that protoplasm occurs in the living parts of all plants.

57. Summary of observations on protoplasm.—While we have by no means exhausted the study of protoplasm, we can, from this study, draw certain conclusions as to its occurrence and appearance in plants. Protoplasm is found in the living and growing parts of all plants. It is a semi-fluid, or slimy, granular, substance; in some plants, or parts of plants, the protoplasm exhibits a streaming or gliding movement of the granules. It is irritable. In the living condition it resists more or less for some time the absorption of certain coloring substances. The water may be withdrawn by glycerine. The protoplasm may be killed by alcohol. When treated with iodine it acquires a yellowish-brown color.

Material.—Freshly formed mycelium of the common black mould (see demonstration 8, which also see for culture material and vessels).

A solution of iodine. A 1% aqueous solution of eosin. 95% alcohol.

Watch glasses to receive small quantities of the solutions when the pupils are engaged in exercise 12.

Microscope, etc.

CHAPTER VI.

HOW WATER MOVES IN AND OUT OF PLANT CELLS.

ABSORPTION, DIFFUSION, OSMOSE.

Demonstration 11.

58. Osmose in spirogyra.—Mount a few threads of the alga spirogyra in a drop of the 5% salt solution on a glass slip, and place on a cover glass for microscopic examination. Let each pupil examine the preparation to observe the protoplasm contracted away from the cell wall. The protoplasmic layer contracts slowly from the cell wall, and the movement of the membrane can be watched by looking through the microscope. The membrane contracts in such a way that all the contents of the cell are finally collected into a rounded or oval mass which occupies the centre of the cell.

Now add fresh water and draw off the salt solution. The protoplasmic membrane expands again, or moves out in all directions, and occupies its former position against the inner surface of the cell wall. This indicates that there is some pressure from within, while this process of absorption is going on, which causes the membrane to move out against the cell wall.

The salt solution draws water from the cell-sap. There is thus a tendency to form a vacuum in the cell, and the pressure on the outside of the protoplasmic membrane causes it to move toward the centre of the cell. When the salt solution is removed and the thread of spirogyra is again bathed with water, the movement of the water is *inward* in the cell. This would suggest that there is some substance dissolved in the cell-sap which does not readily filter out through the membrane, but draws on the water outside. It is this which produces the pressure from within and crowds the membrane out against the cell wall again.

59. Turgescence.—Were it not for the resistance which the cell wall offers to the pressure from within, the delicate protoplasmic membrane would stretch to such an extent that it would

be ruptured, and the protoplasm therefore would be killed. If we examine the cells at the ends of the threads of spirogyra we will see in most cases that the cell wall at the free end is arched outward. This is brought about by the pressure from within upon the protoplasmic membrane which itself presses against the cell wall, and causes it to arch outward. This is beautifully

Fig. 12.
Spirogyra before placing in salt solution.

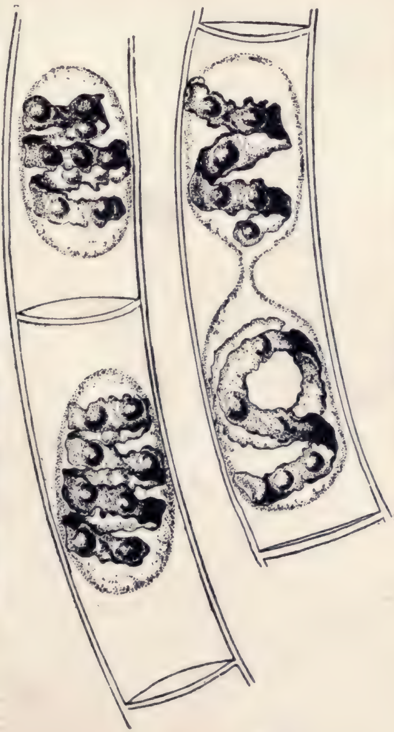

Fig. 13.
Spirogyra in 5% salt solution

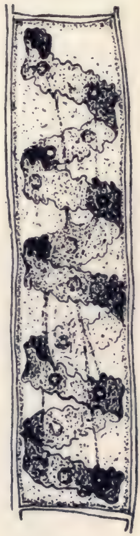

Fig. 14.
Spirogyra from salt solution into water.

shown in the case of threads which are recently broken. The cell wall is therefore *elastic;* it yields to a certain extent to the

pressure from within, but a point is soon reached beyond which it will not stretch, and an equilibrium then tends to be established between the pressure from within on the protoplasmic membrane, and the pressure from without by the elastic cell wall. This state of a cell is *turgescence*, or such a cell is said to be *turgescent*, or *turgid*.

Demonstration 12.

60. Experiment to show diffusion through an animal membrane.—For this experiment use a thistle tube, across the larger end of which should be stretched and tied tightly a piece of bladder membrane. A strong sugar solution (three parts sugar to one part water) is now placed in the tube so that the bulb is filled and the liquid extends part way in the neck of the tube. This is immersed in water within a wide-mouth bottle, the neck of the tube being supported in a perforated cork in such a way that the sugar solution in the tube is on a level with the water in the bottle or jar. In a short while the liquid begins to rise in the thistle tube, in the course of several hours having risen several centimeters. The diffusion current is thus stronger through the membrane in the direction of the sugar solution, so that this gains more water than it loses.

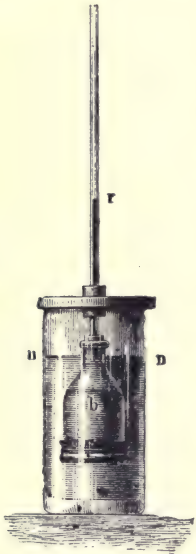

Fig. 15.

61. How diffusion takes place.—We have here two liquids separated by an animal membrane, water on the one hand which diffuses readily through the membrane, while on the other is a solution of sugar which diffuses through the animal membrane with difficulty. The water, therefore, not containing any solvent, according to a general law which has been found to obtain in such cases, diffuses more readily through the membrane into the sugar solution, which thus increases in volume, and also becomes more dilute. The bladder membrane is what is sometimes called a diffusion membrane, since the diffusion currents travel through it. In this experiment then the bulk of the sugar solution is increased, and the

liquid rises in the tube by this pressure above the level of the water in the jar outside of the thistle tube. The diffusion of liquids through a membrane is *osmosis*.

62. Importance of these physical processes in plants.—Now if we recur to our experiment with spirogyra we find that exactly the same processes take place. The proptoplasmic membrane is the diffusion membrane, through which the diffusion takes place. The salt solution which is first used to bathe the threads of the plant is a stronger solution than that of the cell-sap within the cell. Water, therefore, is drawn out of the cell-sap, but the substances in solution in the cell-sap do not readily move out. As the bulk of the cell-sap diminishes the pressure from the outside pushes the protoplasmic membrane away from the wall. Now when we remove the salt solution and bathe the thread with water again, the cell-sap, being a solution of certain substances, diffuses with more difficulty than the water, and the diffusion current is inward, while the protoplasmic membrane moves out against the cell wall, and turgidity again results. Also in the experiments with salt on the tissues and cells of the beet (see exercise 14), the same processes take place.

These experiments not only teach us that in the protoplasmic membrane, the cell wall, and the cell-sap of plants do we have structures which are capable of performing these physical processes, but they also show that these processes are of the utmost importance to the plant, in giving the plant the power to take up solutions of nutriment from the soil.

Exercise 14.

63. To test the effect of a 5% salt solution on a portion of the tissues of a beet.—Select a red beet. Cut several slices about 4*cm* in diameter and about 5*mm* thick. Grasp the slices between the thumb and forefinger and attempt to bend them by light pressure. They are quite rigid and bend but little. Immerse a few of the slices in fresh water and a few in a 5% salt solution. In the course of an hour or less, examine the slices again. Those in the water remain as at first quite rigid, while those in the salt solution are more or less flaccid or limp. They readily bend by pressure between the fingers.

The salt solution, we judge after our experiment with spirogyra, with-

draws some of the water from the cell-sap, the cells thus losing their turgidity and the tissues becoming limp or flaccid from the loss of water.

64. The beet slice becomes rigid again in water.—Now remove some of the slices of the beet from the salt solutions, wash them with water and then immerse them in fresh water. In the course of thirty minutes to one hour, if we examine them again, they will be found to have regained, partly or completely, their rigidity. Here again we infer from the former experiment with spirogyra that the substances in the cell-sap now draw water inward; that is, the diffusion current is inward through the cell walls and the protoplasmic membrane, and the tissue becomes turgid again.

Exercise 15.

65. Turgor is lost when the protoplasm is dead.—Place some slices of a red beet in alcohol; also some in hot water near the boiling point. Do the alcohol and the the hot water become colored? Why? Determine the condition of the

Fig. 16.
Rigid condition of fresh beet section.

Fig. 17.
Limp condition after lying in salt solution.

Fig. 18.
Rigid again after lying in water.

Figs. 16–18.—Turgor and osmosis in slices of beet.

slices by pressure between the fingers. Are they rigid or flaccid? Why? Place them now in fresh cold water. After a quarter of an hour or longer does any change take place as regards their resistance to pressure between the fingers? What is the reason for their remaining in this condition? In what condition must protoplasm be in order to perform the work of a diffusion membrane?

Exercise 16.

66. Osmose experiments with leaves.—Take leaves of various plants, like the geranium, coleus, or seedlings of the squash, pea, or bean, etc.

Immerse the leaves of some in water, and of another set in a 5% salt solution. The petioles of the leaves should not be immersed, for it is desirable to keep the cut ends out of the water or salt solution. In fifteen minutes to half an hour, lift the leaves and seedlings from the water and note the result, and compare. Those which were in the salt solution now rinse in fresh water and immerse for a time in water. Now note the result. Explain the results of this experiment from the results obtained in the previous experiments.

Synopsis.

Movement of water in a single cell.	A strong salt solution draws water out of the cell-sap, and the protoplasmic membrane is pushed inward. The cell becomes *flabby*. Remove the salt and surround the cell with water, and the cell-sap draws water inside again, so that the protoplasmic membrane moves out and presses strongly against the cell wall and the cell becomes *rigid* ("turgid") again. The cell-sap then is a solution of certain salts.
Movement of water in cell masses.	The beet slice is a cell mass, or a mass of tissue. Placed in salt solution some of the water is drawn out of the cell-sap of all the cells by the salt solution; the mass of cells, or the slice, becomes *flabby*. Placed in water it becomes *rigid*, or *turgid*, again. The action is the same as in the single cell, but all the cells act in concert. The action is the same with leaves, and other soft cell masses, or plant parts.

When water and a salt, or sugar, solution are separated by an animal membrane, the current of water is stronger toward the salt, or sugar, solution. The membrane holds back for a time the substance dissolved in the water. So the protoplasmic membrane acts in the same way when it separates two different liquids, where one is a stronger salt than the other, or where one is a salt and the other is water.

When the protoplasm is killed it cannot act as a diffusion membrane.

Material.—Fresh material of spirogyra.

Fresh beets, dark red ones (winter-stored beets are good).

Leafy shoots of some succulent plants, in a fresh condition, or seedlings.

Common table salt, a 5% solution in water.

95% alcohol, and hot water for exercise 15.

Wide-mouth bottle, thistle tube, small piece of bladder membrane, and sugar, for demonstration 12.

Microscope, etc.

CHAPTER VII.

HOW PLANTS OBTAIN THEIR LIQUID FOOD.

I. Water Cultures.

67. How constituents of plant food are determined.—We are now ready to inquire how plants obtain food from the soil or water. Chemical analysis shows that certain mineral substances are common constituents of plants. By growing plants in different solutions of these various substances it has been possible to determine what ones are necessary constituents of plant food. While the proportion of the mineral elements which enter into the composition of plant food may vary considerably within certain limits, the concentration of the solutions should not exceed certain limits. A very useful solution is one recommended by Sachs, and is as follows:

68. Formula for solution of nutrient materials.—The proportions of the ingredients are here given. A larger quantity than 1000*cc* may be needed.

Water	1000 cc.
Potassium nitrate	0.5 gr.
Sodium chloride	0.5 "
Calcium sulphate	0.5 "
Magnesium sulphate	0.5 "
Calcium phosphate	0.5 "

The calcium phosphate is only partly soluble. The solution which is not in use should be kept in a dark cool place to prevent the growth of minute algæ.

Demonstration 13.

69. To prepare the seedlings in water cultures.—Several different plants are useful for experiments in water cultures; peas, corn, or beans are very

good. The seeds of these plants may be germinated, after soaking them for several hours in warm water, by placing them between the folds of wet paper on shallow trays, or in the folds of wet cloth (see demonstration 1). At the same time that the seeds are placed in damp paper or cloth for germination, one lot of the soaked seeds should be planted in good soil and kept under the same temperature conditions, for control. When the plants have germinated one series should be grown in distilled water, which possesses no plant food; another in the nutrient solution, and still another in the nutrient solution to which has been added a few drops of a solution of iron chloride or ferrous sulphate. There would then be four series of cultures which should be carried out with the same kind of seed in each series so that the comparisons can be made on the same species under the different conditions. The series should be numbered and recorded as follows:

No. 1, soil.

No. 2, distilled water.

No. 3, nutrient solution.

No. 4, nutrient solution with a few drops of iron solution added.

70. How to set up the experiment.—Small jars or wide-mouth bottles, or crockery jars, can be used for the water cultures, and the cultures are set up as follows: A cork which will just fit in the mouth of the bottle, or which can be supported by pins, is perforated so that there is room to insert the seedling, with the root projecting below into the liquid. The seed can be fastened in position by inserting a pin through one side, if it is a large one, or in the case of small seeds a cloth of a coarse mesh can be tied over the mouth of the bottle instead of using the cork. After properly setting up the experiments the cultures should be arranged in a suitable place, and observed from time to time during several weeks. In order to obtain more satisfactory results several duplicate series should be set up to guard against the error which might arise from variation in individual plants and from accident. Where there are several students in a class, a single series set up by several will act as checks upon one another. If glass jars are used for the liquid cultures they should be wrapped with black paper or cloth to exclude the light from the liquid, otherwise numerous minute algæ are apt to grow and interfere with the experiment. If crockery jars are used they will not need covering.

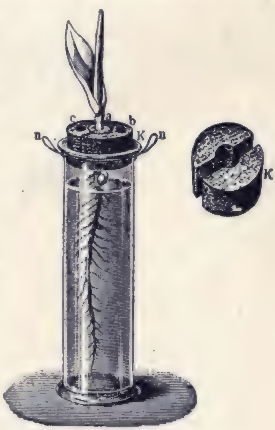

Fig. 19.
Culture cylinder to show position of corn seedling (Hansen).

71. Result of the experiment.—For some time all the plants grow equally well, until the nutriment stored in the seed is exhausted. The numbers 1, 3 and 4, in soil and nutrient solutions, should outstrip number 2, the plants in the distilled water. No. 4 in the nutrient solution with iron, having a perfect food, compares favorably with the plants in the soil.

Exercise 17.

72. Notes on the water cultures.—When the water cultures are set up the members of the class can take notes on them. Then from time to time for several months the plants should be inspected and the members of the class should keep a record of the results, and should not only compare the plants in

Fig. 20. In soil. Fig. 21. Nutrient solution with iron. Fig. 22. Nutrient solution without iron. Fig. 23. In distilled water.

Figures 20–23.—Comparison of growth of pumpkin seedlings, all started at the same time.

the different jars, but should compare them with the plants growing in the soil which were planted at the same time. From these records let each pupil write a complete account of the experiment.

II. How Plants obtain Food from the Soil.

73. Plants take liquid food from the soil.—From these experiments then we judge that such plants take up the food they receive from the soil in the form of a liquid, the elements being in solution in water.

If we recur now to the experiments which were performed with the salt solution on the cells of spirogyra, in the cells of the beet, and the way in which these cells become turgid again when the salt solution is removed and they are again bathed with water, we will have an indication of the way in which plants take up nutrient solutions of food material through their roots.

It should be understood that food substances in solution during absorption diffuse through the protoplasmic membrane independently of each other and also independently of the rate of movement of the water from the soil into the root hairs and cells of the roots. When the cell-sap is poor in certain substances which are dissolved in the surrounding water of the soil, these substances diffuse inwardly more rapidly. But as the cell-sap becomes richer in that particular food substance its further absorption is correspondingly diminished until the cell-sap becomes poorer again, as by diffusion this substance passes on into other cells.

74. How food solutions are carried into the plant.—We can see how the root hairs are able to take up solutions of plant food, and we must next turn our attention to the way in which these solutions are carried further into the plant. We should make a section across the root of a seedling in the region of the root hairs and examine it with the aid of a microscope. We here see that the root hairs are formed by the elongation of certain of the surface cells of the root. These cells elongate perpendicularly to the root, and become *3mm* to *6mm* long. They are flexuous or irregular in outline and cylindrical, as shown in fig. 24. The end of the hair next the root fits in between the adjacent superficial cells of the root and joins closely to the next deeper layer of cells. In studying the section of the young root we see that the root is made up of cells which lie closely side by side, each with its wall, its protoplasm, and cell-sap, the protoplasmic membrane lying on the inside of each cell wall.

Demonstration 14.

75. To show the relation of the root hairs to the other cells of the root.—The teacher can make thin sections of young roots, with a razor, through the region of the root hairs, and mount them for microscopic study for demon-

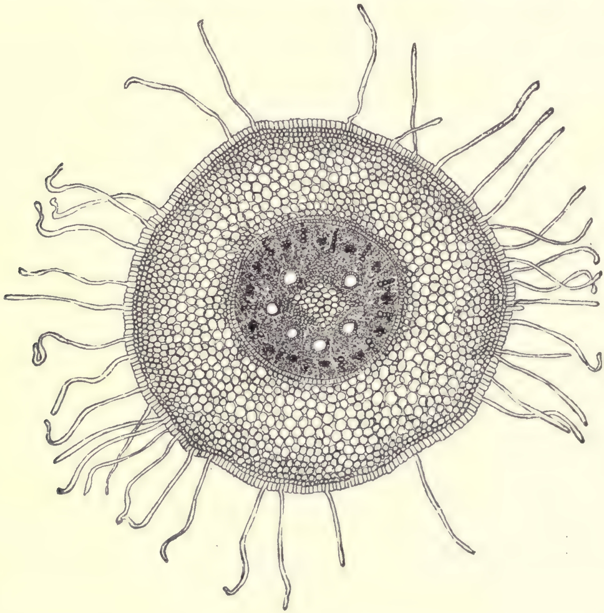

Fig. 24.
Section of corn root, showing rhizoids formed from elongated epidermal cells.

stration before the class. Let each member of the class sketch a portion of the section, to show the root hairs, their relation to the other cells of the root, as well as some of the characters of the tissues of the root.

76. Action of the cell-sap.—In the absorption of the watery solutions of plant food by the root hairs, the cell-sap, being a more concentrated solution, gains some of the former, since the liquid of less concentration flows through the protoplasmic membrane into the more concentrated cell-sap, increasing the bulk of the latter. This makes the root hairs turgid, and at the same time dilutes the cell-sap so that the concentration is not so great. The cells of the root lying inside and close to the base of

the root hairs have a cell-sap which is now more concentrated than the diluted cell-sap of the hairs, and consequently gain some of the food solutions from the latter, which tends to lessen the content of the root hairs and also to increase the concentration of the cell-sap of the same. This makes it possible for the root hairs to draw on the soil for more of the food solutions, and thus, by a variation in the concentration of the substances in solution in the cell-sap of the different cells, the food solutions are carried along until they reach the *vascular bundles*, through which the solutions are carried to distant parts of the plant. In this way a pressure is produced which causes the liquid to rise in the plant.

77. How the root hairs get the watery solutions from the soil.—If we examine the root hairs of a number of seedlings which are growing in the soil under normal conditions, we shall

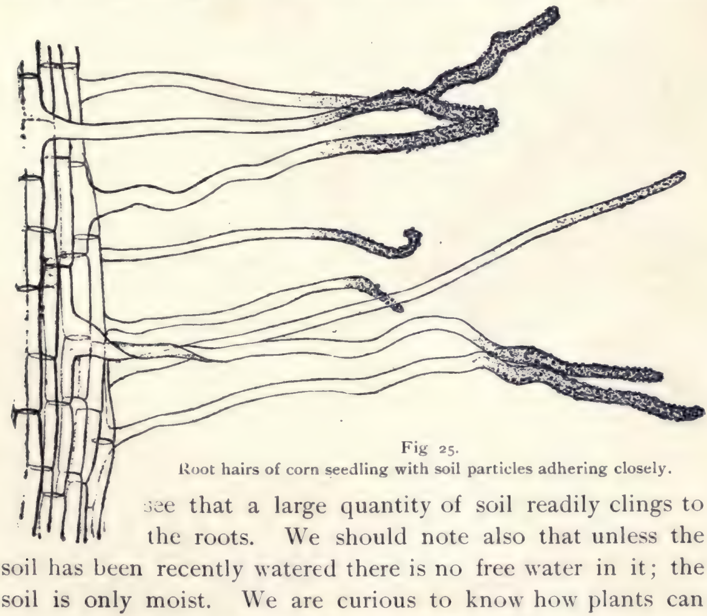

Fig 25.
Root hairs of corn seedling with soil particles adhering closely.

see that a large quantity of soil readily clings to the roots. We should note also that unless the soil has been recently watered there is no free water in it; the soil is only moist. We are curious to know how plants can obtain water from soil which is not wet. If we attempt to wash off the soil from the roots, being careful not to break

away the root hairs, we find that small particles cling so tenaciously to the root hairs that they are not removed. Placing a few such root hairs under the microscope it appears as if here and there the root hairs were glued to the minute soil particles.

In soil most suitable for the growth of land plants the water is not in excess. It is in the form of a thin film surrounding the soil particles. Some of the soil particles being "glued" to the root hairs, this portion of the water film is brought into close contact with the root hairs so that it can be absorbed. Plants cannot remove all the water from the soil.

NOTE.—Some plant food is in solution in the water of the soil, but much of it is in an insoluble form (minute particles, or rocks, containing mineral substances), or in the form of organic matter (as leaves, stems, or other plant parts, or animal matter). The organic matter in the soil is in process of decay because certain microscopic fungi, and especially bacteria, feed upon it and change some of it into a form which can be taken up as food by the higher plant. The insoluble particles, containing mineral substances, are constantly being corroded by the action of certain acids, especially carbonic acid, which is constantly being formed in the soil. The walls of the root hairs are also saturated with this acid, and thus they are able to dissolve some of these mineral substances. This corroding action of the roots can be well shown by placing a small marble plate in a pot; then plant beans or peas on the plate, and cover with earth. In lieu of the marble plate the peas may be planted in clam, or oyster, shells, which are then buried in the soil of the pot, so that the roots from the seedlings will come in contact with the smooth surface of the shell, or of the marble if that is used. After the plants have been growing two or three weeks, remove the soil, and wash the surface of the marble or shell. Hold the surface now toward the window in such a way as to see the light reflected from the surface. The surface has been etched by the action of the roots.

Demonstration 15 (or Exercise).

78. Plants can obtain water from soil which appears dry.—Use small pots with well-grown seedlings. Place the pots in a dry room. Supply no water to the soil. From day to day observe the condition of the soil, and feel of it to note the condition of dryness. Can plants live and grow in a soil which looks and feels dry?

When the plants have wilted remove them from the soil. Weigh the pot of soil. Then place it in an oven and bake it. Weigh again. Has it lost

weight? Can plants remove all the moisture from the soil by absorption through their roots?

Demonstration 15a (or Exercise).

78a. To demonstrate the action of a root hair.—Take a long potato, cut off the ends squarely, and bore a smooth hole from one end nearly through to the other end, being careful not to split the potato. Now pare off the sides to make a tube closed at one end. Rest the closed end in a vessel of water, as shown in fig. 25*a*, after having filled the tube with sugar. After five or six hours examine. The sugar inside of the potato tube draws water inward from the vessel, imitating the action of a root hair.

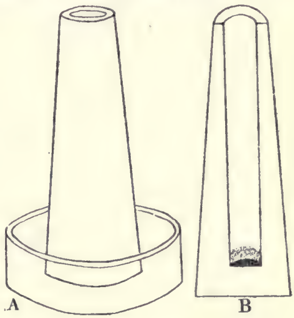

Fig. 25*a*.

A, Potato with central cavity containing sugar, standing in vessel of water. *B*, section of potato tube showing cavity only partly filled with sugar. (After MacDougal.)

Exercise 18.

79. Salt particles cling to root hairs.—Have at hand small pots of seedlings the soil of which is not wet. Pull, or dig, up a seedling. Observe the soil clinging to the roots. Agitate it to remove as much of the soil as possible. Wash the roots by rinsing in water. Are all the soil particles removed? To what portions of the roots does most of the soil cling? Why? Compare with seedlings grown in a germinator free from soil.

III. Strong Solutions of Plant Food are Injurious.

Exercise 19 (or Demonstration).

80. To show the effect on plants of food solutions which are too strong.—Potassium nitrate is one of the food substances used in the water cultures. It is also one of the necessary food substances from which nitrogen is obtained for the plant. Take strongly concentrated solutions, say a 5%, a 10%, and a 20% solution. Label three pots of seedlings to correspond with the solutions. Pour in enough of each solution to the corresponding pots to saturate the soil. In the course of three or four hours (or later) observe the result. Observe the condition of the stems at the surface of the ground. Explain the result in each case. Permit these to remain without watering for a day to see if they will revive. Pour in water and wash through to remove as much of the salt as possible. Set them aside for a day or two. Do they revive? Why?

81. Food solutions which are too strong injure plants instead of benefiting them.—In figures 27 to 33 are shown the results of some experiments with strongly concentrated food solutions. In this case the food substance is potassium nitrate. Solutions of this salt of 2%, 5%, 10%, and 20% were prepared. Three pots of pumpkin seedlings were employed. In one the soil (which was already quite moist in all of the pots) was saturated with the 2%, one with the 10%, and the other with the 20% solution. In a few hours the seedlings in pots 31 and 32 had collapsed, while those in pot 30 were still rigid. The salt in 31 and 32, being, even when diluted with the water in the soil, stronger than the salts in the cell-sap, withdrew water from the root hairs, roots, and from the lower part of the stems, so that the plants lost their rigidity. The lower part of the stems was flabby. The plants were then photographed as shown in figures 30–32. Some of the 5% solution was then added to pot 30. In four hours (at 6 P.M.) two of the seedlings showed signs of collapse. On the following morning these two had collapsed, and the photograph of the result is shown in figure 33.

Fig. 26.
Pumpkin seedling removed from soil to show earth clinging to roots.

Synopsis.—Plants obtain their food either in a liquid or a gaseous form.

Plants obtain their liquid food (mostly certain mineral and nitrogenous substances) by absorption.

Fig. 27.
2% solution potassium nitrate.

Fig. 28.
10% solution potassium nitrate.

Fig. 29.
20% solution potassium nitrate.

Figures 27–29.—Pumpkin seedlings, soil watered with solution of potassium nitrate of different strengths. Photographed immediately after the application of the solution to the soil.

Fig. 30.
2% solution potassium nitrate.

Fig. 31.
10% solution potassium nitrate.

Fig. 32.
20% solution potassium nitrate.

Figures 30–32.—Pumpkin seedlings, soil watered with solution of potassium nitrate of different strengths. Photographed four hours after application of the solution to the soil.

Plants having a root system in comparatively dry ground absorb their liquid food through root hairs and roots.

Aquatic plants (plants in water) absorb liquid food through nearly the entire surface in contact with the water.

The plant food must be in a very dilute solution; a strong solution injures the plant, and, if too strong, will kill the plant, because by the law of diffusion the water in the plant is removed to such an extent that the plant becomes flabby, and if turgor is not restored, the plant will die.

Fig. 33.

Pot in which the 2% solution was poured. After four hours a 5% solution of potassium nitrate was added. This caused two of the seedlings to collapse after about ten hours. Photographed eighteen hours after last application.

Soil which is not saturated with water, i.e., that which is only moist, or even which may seem dry, still contains water which forms a thin film (capillary film) around the soil particles.

The root hairs become firmly fixed to certain of the soil particles and are thus brought in close contact with the water film which contains mineral and nitrogenous food in solution. This film is continuous from one soil particle to another in soil of the right texture and physical properties, and thus as the root hairs absorb that portion of the film in contact with them, by capillarity the film draws more water through the soil from moist places.

Materials:—Potassium nitrate, sodium chloride, calcium sulphate, magnesium sulphate, calcium phosphate, for nutrient solution as per paragraph 68. A larger amount of potassium nitrate (saltpetre) for exercise 19.

Wide-mouth bottles, or small crockery jars, with perforated corks to fit, for the water culture.

Seedlings started in a germinator.

Seedlings, grown in pots, two or three weeks old, for exercises 17 and 18.

One or more long potatoes ; sugar.

Microscope, etc. Razor.

CHAPTER VIII.

HOW SOME PLANT PARTS REMAIN RIGID.

82. Turgidity of plant parts.—In Chapter VI we found that the turgescence of a cell depends on the absorption of water by

Fig. 34.
Indian turnip plant just removed from the soil. It is rigid.

Fig. 35.
Same plant half an hour later. It is becoming limp.

protoplasm. The protoplasm permits the cell-sap to draw the water inward by diffusion, but the protoplasmic membrane does not permit the water to filter out readily, and the outward pressure

of the protoplasm on the elastic cell wall makes the cell turgid. So we found in the experiments with the slices of beet in the salt solution and water that the partial removal of the water from the beet leaves the slices limp, while they regain their rigidity if the salt solution is removed and the slices are placed in water. We should now endeavor to see if water plays any part in the rigidity of plant parts, as in the case of shoots, leaves, etc., and in what way this rigidity may be lost and regained.

Exercise 20.

83. Loss of turgidity in cut shoots.—From a living geranium, balsam, coleus, or other plant, cut a leafy shoot 15*cm* to 20*cm* long. Leave it in a dry room for a short while until it partly wilts. Grasp the shoot at the cut end and attempt to hold it erect. How does it now compare with its condition when first cut from the plant?

84. Restoration of turgidity in shoots.—Take the leafy shoot used in paragraph 83. (It should not be so wilted that any portion of it is dry.) Cut the end fresh again and place it in a vessel of water, and if the room is dry, cover the vessel and shoot with a tall glass cylinder or bell jar. Observe the result in a few hours, or on the following day.

Fig. 36.
Same plant photographed four hours later. It has revived.

85. Longitudinal tissue tension.—For this in early summer one may use the young and succulent shoots of the elder (sambucus); or the petioles of rhubarb during the summer and early autumn; or the petioles of richardia. Petioles of caladium are

excellent for this purpose, and these may be had at almost any season of the year from the greenhouses, and are thus especially advantageous for work during late autumn or winter. The tension is so strong that a portion of such a petiole 10–15*cm* long is ample to demonstrate it. As we grasp the lower end of the petiole of a caladium, or rhubarb leaf, we observe how rigid it is, and how well it supports the heavy expanded lamina of the leaf.

Fig. 37. Centre of petiole. Fig. 38. Outside strip. Fig. 39. Outside strip attached to centre.

Figures 37–39. Showing longitudinal tissue tension.

Exercise 21.

86. To demonstrate the tissue tension.—Take a portion of the petiole of a caladium, or of celery, or other plant, about 15*cm* long. Cut the ends off squarely. With a knife strip off a layer from the outside about 2–3*mm* in thickness, and the full length of the piece. Now attempt to replace it, comparing the length of each part. Remove another strip lying next this one, and so on until all the outer portion has been removed. Describe what takes place as the successive strips are removed. When all are removed, compare an outside strip with the central portion. What has happened? Is there now a greater difference in length between the outside strip and the central portion? What is the cause of this? Describe the tensions in the outside and inner portion of the petiole.

Cut a section of the petiole about 8*cm* long, remove strips on two opposite sides and split the remainder down the middle, securing two pieces with the center and outside portion attached. Place one of these in fresh water and the other in a 5 per cent salt solution and note the result. If convenient treat celery petioles in the same way. The flower stems of dandelions split into quarters are excellent objects to compare when placed in water, and in a 5 per cent salt solution.

Exercise 22.

87. Transverse tissue tension.—To show this take a willow shoot 3–5*cm* in diameter and saw off sections about 2*cm* long. Cut through the bark on one side, and peel off the bark in one piece carefully. Now attempt to replace it. What has happened? Describe the tension.

Demonstration 16.

88. Importance of tissue tension.—To demonstrate the efficiency of this tension in giving support, let us take a long petiole of caladium or of rhubarb. Hold it by one end in a horizontal position. It is firm and rigid, and does not droop, or but little. Remove all of the outer portion of the tissues, as described above, leaving only the central portion. Now attempt to hold it in a horizontal position by one end. It is flabby and droops downward because the longitudinal tension is removed. (See figs. 40, 41.)

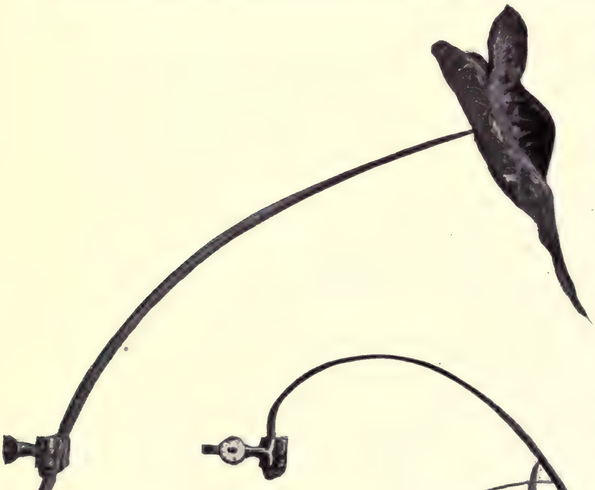

Fig. 40.
Caladium leaf petiole rigid from longitudinal tensions.

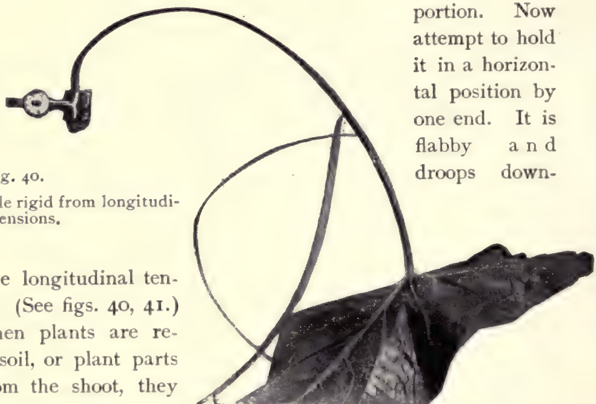

Fig. 41.
Same leaf, longitudinal tension partly removed by the loss of two outside strips.

Synopsis.—When plants are removed from the soil, or plant parts are removed from the shoot, they soon become flabby and limp.

When these partly wilted plants are placed with the stems in water, they may become rigid again by the absorption of water and the restoration of the rigidity of the cells.

Longitudinal tissue tension.	Succulent stems and petioles are often kept rigid because of a pull, or tension, of different layers of cells in opposite directions. The outer layers of cells tend to shorten, while the inner cells tend to lengthen. These opposite tensions, or pulls, make the shoot rigid. The cells of the shoots must be turgid with water or the tension is not present.
Transverse tissue tension.	This occurs where the outer layers of tissue are stretched transversely instead of longitudinally.

Material.—If fresh plants cannot be obtained out-doors, use leafy shoots of rather succulent plants from the green-house, like the coleus plant, garden balsam, or leaves with long petioles like the caladium of the green-house, or stored celery. The shoots should not be cut from the plant until the pupil is ready to begin the exercise. Wide-mouthed bottles, filled with water, and if necessary some bell jars (one large bell jar will answer for several students).

CHAPTER IX.

HOW WATER MOVES THROUGH THE PLANT.

I. Root Pressure, or Osmotic Pressure.

89. Flow of water from pruned vines.—It is a very common thing to note, when certain shrubs or vines are pruned in the spring, the exudation of a watery fluid from the cut surfaces. In the case of the grape vine this has been known to continue for a number of days, and in some cases the amount of liquid, called "sap," which escapes is considerable. In many cases it is directly traceable to the activity of the roots, or root hairs, in the absorption of water from the soil. For this reason the term *root pressure* is used to denote the force exerted in supplying the water from the soil.

90. Root pressure may be measured.—It is possible to measure not only the amount of water which the roots will raise in a given time, but also to measure the force exerted by the roots during root pressure. It has been found that root pressure in the case of the nettle is sufficient to hold a column of water about 4.5 meters (15 ft.) high (Vines), while the root pressure of the vine (Hales, 1721) will hold a column of water about 10 meters (36.5 ft.) high, and the birch (Betula lutea) (Clark, 1873) has a root pressure sufficient to hold a column of water about 25 meters (84.7 ft.) high.

Demonstration 17.

91. To demonstrate root pressure.—Use a potted begonia or balsam, the latter being especially useful. The plants are usually convenient to obtain from the greenhouses, to illustrate this phenomenon. Cut off rather close to

the soil and attach a long glass tube to the cut end of the stem, still connected with the roots, by the use of rubber tubing as shown in figure 42. A very small quantity of water may be poured in to moisten the cut end of the stem. In a few minutes the water begins to rise in the glass tube. In some cases it rises quite rapidly, so that the column of water can readily be seen to extend higher and higher up in the tube when observed at quite short intervals. The height of this column of water is a measure of the force exerted by the roots. The pressure force of the roots may be measured also by determining the height to which it will raise a column of mercury.

Fig. 42. Experiment to show root pressure. (Detmer.)

Exercise 23.

92. To make records of the experiment.—The pupils can take notes on the experiment at the time it is set up. Then for several days let them keep a record of the height of the liquid in the tube, taken at several times a day if possible.

93. Variation in root pressure.—In either case where the experiment is continued for several days it is noticed that the column of water or of mercury rises and falls at different times during the same day, that is, the column stands at varying heights; or in other words the root pressure varies during the day. With some plants it has been found that the pressure is greatest at certain times of the day, or at certain seasons of the year. Such variation of root pressure exhibits what is termed a periodicity, and in the case of some plants there is a daily periodicity; while in others there is in addition an annual periodicity. With the grape vine the root pressure is greatest in the forenoon, and decreases from 12–6 P.M., while with the sunflower it is greatest before 10 A.M., when it begins to decrease. Temperature of the soil is one of the most important external conditions affecting the activity of root pressure.

II. The Loss of Water by Plants (Transpiration).

94. Wilting of cut shoots.—We should now inquire if all the water which is taken up in excess of that which actually suffices

for turgidity is used in plant growth and in the increase of plant substance. We notice when a leaf or shoot is cut away from a plant, unless it is kept in quite a moist condition, or in a damp, cool place, that it becomes flaccid, and droops. It wilts, as we say. The leaves and shoot lose their turgidity. This fact suggests that there has been a loss of water from the shoot or leaf. It can be readily seen that this loss is not in the form of drops of water which issue from the cut end of the shoot or petiole. What then becomes of the water in the cut leaf or shoot ?

Exercise 24.

95. Loss of water from excised leaves.—Take a handful of fresh, green, rather succulent leaves, which are free from water on the surface, and place them under a glass bell jar, which is tightly closed below but which contains

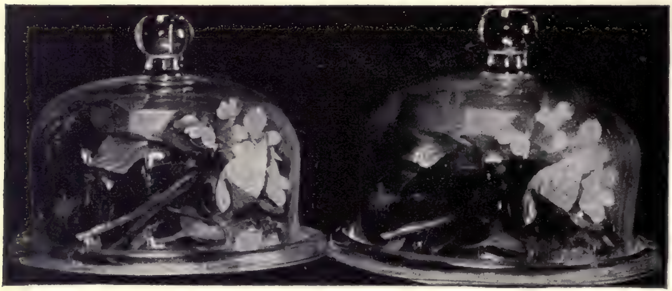

Fig. 43.
Leafy shoots just covered with dry bell jar.

Fig. 44.
The same after four hours; mist shows on inside of jar.

Figures 43, 44.—Experiment to show transpiration from leaves on cut shoots.

no water. Place this in a brightly lighted window, or in sunlight. In the course of fifteen to thirty minutes notice that a thin film of moisture is accumulating on the inner surface of the glass jar. After an hour or more the moisture has accumulated so that it appears in the form of small drops of condensed water. Set up at the same time a bell jar in exactly the same way but which contains no leaves. In this jar there will be no condensed moisture on the inner surface. We thus are justified in concluding that the moisture in the former jar comes from the leaves. Since there is no visible

water on the surfaces of the leaves, or at the cut ends, before it may have condensed there, we infer that the water escapes from the leaves in the form of *water vapor*, and that this water vapor, when it comes in contact with the

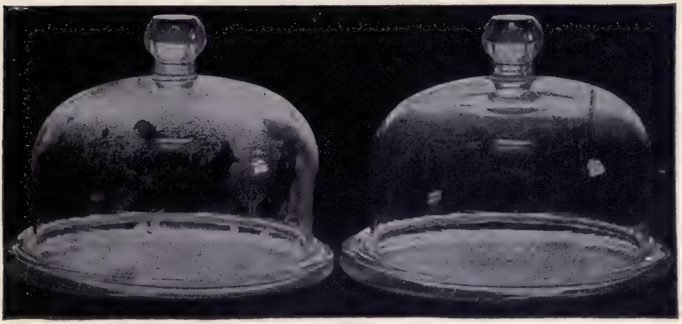

Fig. 45.
Leaves removed to show drops of water on inside of jar.

Fig. 46.
Photographed after the water has been wiped from inside of jar.

surface of the cold glass, condenses and forms the moisture film, and later the drops of water. The leaves of these cut shoots therefore lose water in the form of water vapor, and thus a loss of turgidity results.

Demonstration 18.

96. Loss of water from growing plants.—Suppose we now take a small and actively growing plant in a pot, and cover the pot and the soil with a sheet of rubber cloth which fits tightly around the stem of the plant (or the pot and soil may be enclosed in a hermetically sealed vessel) so that the moisture from the soil cannot escape. Then place a bell jar over the plant, and set in a brightly lighted place, at a temperature suitable for growth. In the course of a few minutes on a dry day a moisture film forms on the inner surface of the glass, just as it did in the case of the glass jar containing the cut shoots and leaves. Later the moisture has condensed so that it is in the form of drops. If we have the same leaf surface here as we had with the cut shoots, we will probably find that a larger amount of water accumulates on the surface of the jar from the plant that is still attached to its roots.

97. Water escapes from the surfaces of living leaves in the form of water vapor.—This living plant then has lost water, which also escapes in the form of water vapor. Since here there

are no cut places on the shoots or leaves, we infer that the loss of water vapor takes place from the surfaces of the leaves and from the shoots. It is also to be noted that, while this plant is losing water from the surfaces of the leaves, it does not wilt or lose its turgidity. The roots by their activity and osmotic pressure supply water to take the place of that which is given off in the form of water vapor. This loss of water in the form of water vapor by plants is *transpiration.*

Synopsis.

Root pressure or osmotic pressure.
- As a result of the law of diffusion by which water from the soil is drawn inside the root hairs forcibly by the cell-sap, and is passed on through the cells of the root by the same law of diffusion, a pressure occurs which causes the liquid plant food to rise to some extent in the roots and stems of plants.
- The height to which water can be lifted by root pressure varies in different plants.
- Root pressure is not constant throughout the day in a given plant, but varies.
- Root pressure is usually lower at night and higher toward midday.
- Plants then show a daily periodicity in the strength of the root pressure, but the periods are not coincident in all plants; that is, the time of day when one plant shows the greatest root pressure is not necessarily the same for another plant.
- Some plants also show an annual periodicity in the strength of the root pressure.

Transpiration.
- Living plants are constantly losing water by evaporation (or transpiration) from the surface, unless the air is saturated with moisture.
- If plants are removed from the soil, or shoots are cut away, they "wilt," or become flabby, because of the loss of water.
- This loss of water from plants, or plant parts, can be demonstrated by placing the plant under a glass receiver.
- The water escapes in the form of invisible water vapor.
- When the plant is growing normally, the roots by absorption of water from the soil supply water to take the place of that evaporated from the exposed plant surface.

Material.—For root pressure: One or more potted plants like a begonia, garden balsam, etc. A long glass tube about the same diameter as that of the plant stem; some rubber tubing to connect the glass with the stem, and to connect sections of tubing if necessary.

For transpiration: Some succulent leaves and leafy shoots, like geranium, coleus, balsam, etc. Some small glass bell jars. A potted coleus plant (or balsam), some sheet rubber to cover the pot and earth closely, and a bell jar to cover the plant.

CHAPTER X.

HOW WATER MOVES THROUGH THE PLANT— CONCLUDED.

III. PART WHICH THE LEAF PLAYS IN TRANSPIRATION.

Demonstration 19.

93. **Structure of a leaf.**—We are now led to inquire why it is that a living leaf loses water less rapidly than dead ones, and why less water escapes from a given leaf surface than from an equal surface of water. To understand this it will be necessary to examine the minute structure of a leaf. For this purpose we will select the leaf of an ivy, though many other leaves will answer equally well. From a portion of the leaf we should make very thin cross-sections with a razor or other sharp instrument. These sections should be perpendicular to the surface of the leaf, and should be then mounted in water for microscopic examination.*

Fig. 47.
Section through ivy leaf showing communication between stomate and the large intercellular spaces of the leaf; stoma closed.

Let the pupils examine the preparations and make sketches of the structure of the leaf, naming the different kinds of cells, and describing the function of the different groups of cells. (See paragraphs 99–101.)

99. **Epidermis of the leaf.**—In this section we see that the green part of the leaf is bordered on what are its upper and lower surfaces by a row of cells which possess no green color. The walls of the cells of each row have nearly parallel sides, and the cross walls are perpendicular. These cells form a single layer over both sur-

* Demonstrations may be made with prepared sections of leaves.

faces of the leaf and are termed the *epidermis*. Their walls are quite stout and the outer walls are *cuticularized*.

100. Soft tissue of the leaf.—The cells which contain the green chlorophyll bodies are arranged in two different ways. Those on the upper side of the leaf are usually long and prismatic in form and lie closely parallel to each other. Because of this arrangement of these cells they are termed the *palisade* cells, and form what is called the *palisade layer*.

Fig. 48.
Stoma open.

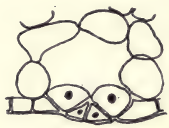

Fig 49.
Stoma closed.

Figures 48, 49.—Section through stomata of ivy leaf.

The other green cells, lying below, vary greatly in size in different plants and to some extent also in the same plant. Here we notice that they are elongated, or oval, or somewhat irregular in form. The most striking peculiarity, however, in their arrangement is that they are not usually packed closely together, but each cell touches the other adjacent cells only at certain points. This arrangement of these cells forms quite large spaces between them, the intercellular spaces. If we should examine such a section of a leaf before it is mounted in water we would see that the intercellular spaces are not filled with water or cell-sap, but are filled with air or some gas. Within the cells, on the other hand, we find the cell-sap and the protoplasm.

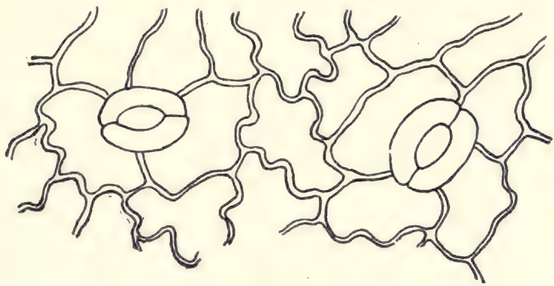

Fig. 50.
Portion of epidermis of ivy, showing irregular epidermal cells, stoma and guard cells.

101. Stomata.—If we examine carefully the row of epidermal cells on the under surface of the leaf, we will find here and there a peculiar arrangement of cells shown at figs. 47–49. This opening through the epidermal layer is a *stoma*. The cells which immediately surround the openings are the *guard cells*. The form of the guard cells can be better seen if we tear a leaf in such a way as to strip off a short piece of the lower epidermis, and mount this in water. The guard cells are nearly crescent shaped, and the stoma is elliptical in outline. The epidermal cells are very irregular in outline in this view. We should also note that while the epidermal cells contain no chlorophyll, the guard cells do.

102. The living protoplasm retards the evaporation of water from the leaf.—If we now take into consideration a few facts which we have learned in a previous chapter, with reference to the physical properties of the living cell, we will be able to give a partial explanation of the comparative slowness with which the water escapes from the leaves. The inner surfaces of the cell walls are lined with the membrane of protoplasm, and within this is the cell-sap. These cells have become turgid by the absorption of the water which has passed up to them from the roots. While the protoplasmic membrane of the cells does not readily permit the water to filter through, yet it is saturated with water, and the elastic cell wall with which it is in contact is also saturated. From the cell wall the water evaporates into the intercellular spaces. But the water is given up slowly through the protoplasmic membrane so that the water vapor cannot be given off as rapidly from the cell walls as it could if the protoplasm were dead. The living protoplasmic membrane then, which is only slowly permeable to the water of the cell-sap, is here a very important factor in checking the too rapid loss of water from the leaves.

103. Communication through intercellular spaces.—By an examination of our leaf section we see that the intercellular

spaces are all connected, and that the stomata, where they occur, open also into intercellular spaces. There is here an opportunity for the water vapor in the intercellular spaces to escape when the stomata are open.

104. Action of the stomata.—Besides permitting the escape of the water vapor when the stomata are open they serve a very important office in regulating the amount of transpiration. During normal transpiration the stomata remain open, that is, when the amount of transpiration from the leaf is not in excess of the supply of water to the leaves. But when the transpiration from the leaves is in excess, as often happens, and the air becomes very dry, the stomata close, and thus the rapid transpiration is checked.

For further discussion of transpiration and root pressure see the author's larger "Elementary Botany."

Synopsis.

Structure of a leaf (cross-section).

- Epidermis. The epidermal cells usually lack chlorophyll.
  - Upper epidermis, a layer of cells over the upper surface of the leaf.
  - Lower epidermis, a layer of cells over the lower surface of the leaf.
  - Guard cells of the stomates (openings in the epidermis) contain chlorophyll.
  - (Hairs of various kinds on different leaves are often present: see synopsis of tissues at close of Chapter XI.)
- Mesophyll (the cells of the leaf between the upper and lower epidermis).
  1. Palisade layer of cells, usually next the upper epidermis. Contains chlorophyll.
  2. Loose parenchyma cells, with large intercellular spaces where the air and water vapor can circulate. Cells contain chlorophyll.
- (Vascular bundles are present in the "veins" of the leaf: see Chapter XI.)

Function of the leaf in transpiration.	
	The living protoplasm retards the evaporation of water somewhat from the cells.
	The water escapes from the cells of the middle part of the leaf into the intercellular spaces. From here it passes out through the openings (stomates).
	When transpiration is in excess of root pressure, the guard cells close together and shut the opening, and thus greatly retard the loss of water.
	The cuticle, a thin deposit on the outer surface of the epidermal cells, also retards more or less transpiration.

Material.—Fresh leaves of some plant like begonia, ivy, or other leaf which is easy to section. Where preferred, permanently mounted slides of sections of leaves may be used.

CHAPTER XI.

PATH OF MOVEMENT OF LIQUIDS IN PLANTS.

105. Course of the liquids through the stems.—In our study of root pressure and transpiration we have seen that large quantities of water or solutions move upward through the stems of plants. We are now led to inquire through what part of the stems the liquid passes in this upward movement, or in other words, what is the path of the "sap" as it rises in the stem. This we can readily see by the following trial.

Demonstration 20.

106. To show the tracts through which the liquids rise.—Cut off leafy shoots of various plants and insert the cut ends in a vessel of water to which has been added a few crystals of the dye known as fuchsin to make a deep red color (other red dyes may be used, but this one is especially good). If the study is made during the summer, the "touch-me-not" (impatiens) will be found a very useful plant, or the garden balsam, which may also be had in the winter from conservatories. Almost any plant will do, however, but we should also select one like the corn plant (Zea mays) if in the summer.

107. These solutions color the tracts in the stem and leaves through which they flow.—After a few hours in the case of the impatiens, or the more tender plants, we can see through the stem that certain tracts are colored red by the solution, and after 12 to 24 hours there may be seen a red coloration of the leaves of some of the plants used. After the shoots have been standing in the solution for a few hours, if we cut them at various places we shall note that there are several points in the section where the tissues are colored red. In the impatiens

perhaps from four to five, in the sunflower a larger number. In these plants the colored areas on a cross-section of the stem are situated in a concentric ring which separates more or less completely an outer ring of the stem from the central portion. If we now split portions of the stem lengthwise we see that these colored areas continue throughout the length of the stem, in some cases even up to the leaves and into them.

108. Arrangement of the tracts in the corn stalk.—If we cut across the stem of a corn plant which has been in the solu-

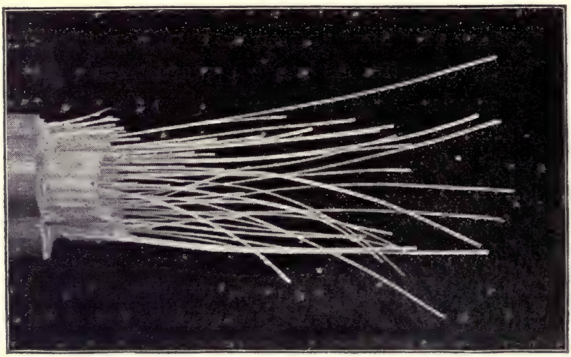

Fig. 51.
Broken corn stalk, showing fibro-vascular bundles.

tion, we see that instead of the colored areas being in a concentric ring they are irregularly scattered, and on splitting the stem we see here also that these colored areas extend for long distances through the stem.

Exercise 25.

109. To demonstrate the tracts in stems and petioles.—Take leaves of a calla lily, or of a caladium, which grow in conservatories, and good leaves of stored celery, with long petioles. Other leafy shoots which are more accessible may be used, if desired. Place the ends of the petioles, or the shoots, in a solution of fuchsin, or in red ink. In the course of an hour (they may be left in a longer time if necessary) observe the petioles and leaves. Can any of the color be seen without cutting into the stem? (Where the

shoots remain in the colored liquid for a day, or even for a less time, portions of the leaves will show the color.) Cut across the stems, and describe the location of the colored areas. Split the petioles or stems and trace the colored tracts. Compare their location in the calla and the celery petiole.

110. To observe the texture of these areas in a celery petiole.—Take fresh but rather old celery leaves (from stored celery if in the winter). Break the petiole apart. Is the broken part ragged? Is there any difference in the texture or toughness of the petiole shown by any portions "stringing" out? Describe the location of these strands. What are they? Have they any relation to the colored areas or tracts in the petiole which was in the red ink? Break apart in a similar way a petiole which has been in the red ink. Compare. The celery represents a dicotyledenous plant.

111. The strands in a dead corn stalk.—Take a dead corn stalk (they are easily obtained in the autumn or winter from the fields). Cut through the outer harder portion of the stem. Break it. Compare carefully with the broken celery petiole. The corn stem represents a monocotyledonous plant.

112. There are definite courses through which the liquids rise.—We thus see that instead of the liquids passing through the entire stem they are confined to definite courses. Now that we have discovered the path of the upward movement of water in the stem, we are curious to see what the structure of these definite portions of the stem is.

Demonstration 21.

113. Structure of the fibrovascular bundle.—Make quite thin cross-sections of the stem it is desired to study, and mount in water for microscopic examination. Permanent mounts may be made in Canada balsam by those who understand the method. Or mounted preparations may be obtained, which will preserve for future use. Let each pupil examine cross and longitudinal sections of a dicotyledon and of a monocotyledon, making out clearly the different groups of tissues, and the kinds of cells composing them. Paragraphs 114–123 may be used as a guide. The description is here made from the castor-oil bean, and the illustration from the sunflower to represent the dicotyledon, while the corn stem is used to illustrate the monocotyledon. It will be no disadvantage for the teacher to use other plants than those employed here for the demonstration.

114. The bundles in a dicotyledon.—To illustrate the structure of the bundle in one type we may take the stem of the castor-oil bean. On examining these cross-sections we see that there are groups of cells which are denser than the ground tissue. These groups correspond to the colored areas in the former experiments, and are the vascular bundles cut across. These groups

are somewhat oval in outline, with the pointed end directed toward the centre of the stem. If we look at the section as a whole we see that there is a nar-

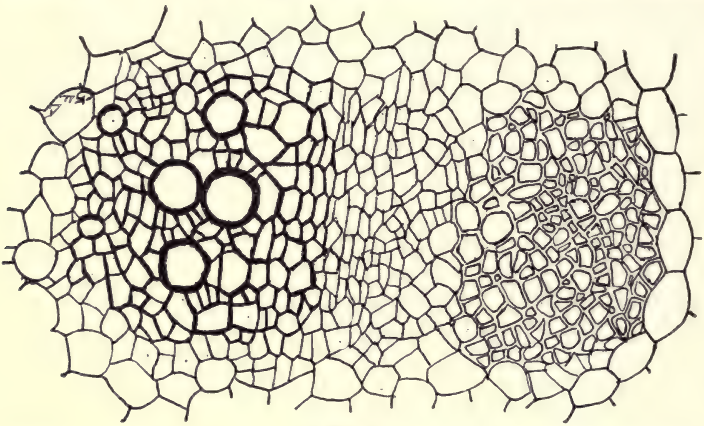

Fig. 52.
Xylem portion of bundle. Cambium portion of bundle. Bast portion of bundle.
Section of vascular bundle of sunflower stem.

row continuous ring * of small cells situated at the same distance from the centre of the stem as the middle part of the bundles, and that it divides the bundles into two groups of cells.

115. Woody portion of the bundle.—In that portion of the bundle on the inside of the ring, i.e., toward the "pith," we note large, circular, or angular cavities. The walls of these cells are quite thick and woody. They are therefore called wood cells, and because they are continuous with cells above and below them in the stem in such a way that long tubes are formed, they are called woody vessels. Mixed in with these are smaller cells, some of which also have thick walls and are wood cells. Some of these cells may have thin walls. This is the case with all when they are young, and they are then classed with the fundamental tissue or soft tissue (parenchyma). This part of the bundle, since it contains woody vessels and fibres, is the *wood portion* of the bundle, or technically the *xylem*.

* This ring and the bundles separate the stem into two regions, an outer one composed of large cells with thin walls, known as the cortical cells, or collectively the *cortex*. The inner portion, corresponding to what is called the pith, is made up of the same kind of cells and is called the *medulla*, or *pith*. When the cells of the cortex, as well as of the pith, remain thin-walled the tissue is called parenchyma. Parenchyma belongs to the group of tissues called fundamental.

116. Bast portion of the bundle.—If our section is through a part of the stem which is not too young, the tissues of the outer part of the bundle will show either one or several groups of cells which have white and shiny walls, that are thickened as much or more than those of the wood vessels. These cells are *bast* cells, and for this reason this part of the bundle is the *bast* portion, or the *phloem*. Intermingled with these, cells may often be found which have thin walls, unless the bundle is very old. Nearer the centre of the bundle and still within the bast portion are cells with thin walls, angular and irregularly arranged. This is the softer portion of the bast, and some of these cells are what are called *sieve* tubes, which can be better seen and studied in a longitudinal section of the stem.

117. Cambium region of the bundle.—Extending across the centre of the bundle are several rows of small cells, the smallest of the bundle, and we can see that they are more regularly arranged, usually in quite regular rows, like bricks piled upon one another. These cells have thinner walls than any others of the bundle, and they usually take a deeper stain when treated with a solution of some of the dyes. This is because they are younger, and are therefore richer in protoplasmic contents. This zone of young cells across the bundle is the *cambium*. Its cells grow and divide, and thus increase the size of the bundle. By this increase in the number of the cells of the cambium layer, the outermost cells on either side are continually passing over into the phloem, on the one hand, and into the wood portion of the bundle, on the other hand.

118. Longitudinal section of the bundle.—If we make thin longisections of the vascular bundle of the castor-oil seedling (or other dicotyledon) so that we have thin ones running through a bundle radially, as shown in fig. 53, we can see the structure of these parts of the bundle in side view. We see here that the form of the cells is very different from what is presented in a cross-section of the same. The walls of the various ducts have peculiar markings on them. These markings are caused by the walls being thicker in some places than in others, and this thickening takes place so regularly in some instances as to form regular spiral thickenings. Others have the thickenings in the form of the rounds of a ladder, while still others have pitted walls or the thickenings are in the form of rings.

119. Vessels or ducts.—One way in which the cells in side view differ greatly from an end view, in a cross-section in the bundle, is that they are much longer in the direction of the axis of the stem. The cells have become elongated greatly. If we search for the place where two of these large cells with spiral, or ladder-like, markings meet end to end, we shall see that the wall which formerly separated the cells has nearly or quite disappeared. In other words the two cells have now an open communication at the ends. This is so for long distances in the stem, so that long columns of these large

cells form tubes or vessels through which the water rises in the stems of plants.

120. Bast fibres.—In the bast portion of the bundle we detect the cells of the bast fibres by their thick walls. They are very much elongated and the

Fig. 53.
Longitudinal section of vascular bundle of sunflower stem; spiral. scalariform and pitted vessels at left; next are wood fibers with oblique cross walls; in middle are cambium cells with straight cross walls, next two sieve tubes, then phloem or bast cells.

ends taper out to thin points so that they overlap. In this way they serve to strengthen the stem.

121. Sieve tubes.—Lying near the bast cells, usually toward the cambium, are elongated cells standing end to end, with delicate markings on their cross-walls which appear like finely punctured plates or sieves. The protoplasm in such cells is usually quite distinct, and sometimes contracted away from the side walls, but attached to the cross-walls, and this aids in the detection of the sieve tubes (fig. 53). The granular appearance which these plates present is caused by minute perforations through the wall so that there is a communication between the cells. The tubes thus formed are therefore called sieve tubes, and they extend for long distances through the bundle so that there is communication throughout the entire length of the stem. (The function of the sieve tubes is supposed to be that for the downward transportation of substances elaborated in the leaves.)

122. Bundle in the sunflower stem.—In like manner a section of the stem of the sunflower shows similar bundles, but the number is greater than eight. In the garden balsam the number is from four to six in an ordinary stem 3–4*mm* diameter. Here we can see quite well the origin of the vascular bundle. Between the larger bundles especially in free-hand sections of stems

through which a colored solution has been lifted by transpiration, we can see small groups of the minute cells in the cambial ring which are colored. These groups of cells which form strands running through the stem are *procambium strands.* The cells divide and increase just like the cambium cells, and the older ones thrown off on either side change, those toward the centre of the stem to wood vessels and fibres, and those on the outer side to bast cells and sieve tubes.

123. Fibrovascular bundles in the Indian corn.—In fig. 54 is represented a fibrovascular bundle of the stem of the Indian corn. The large cells are those of the spiral and reticulated and annular vessels. This is the woody portion of the bundle, or xylem. Opposite this is the bast portion or phloem, marked by the lighter colored tissue at *i*. The larger of these cells are the sieve tubes, and intermingled with them are smaller cells with thin walls. Surrounding the entire bundle are small cells with thick walls. These are elongated and the tapering ends overlap. They are thus slender and long and form fibres. In such a bundle all of the cambium has passed over into permanent tissue and the bundle is said to be closed.

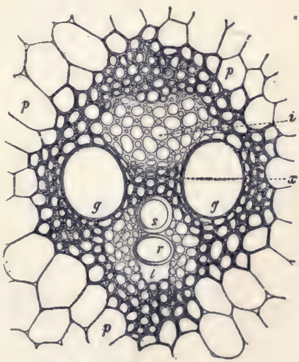

Fig. 54.

Transection of fibrovascular bundle of Indian corn. *a*, toward periphery of stem; *g*, large pitted vessels; *s*, spiral vessel; *r*, annular vessel; *l*, air cavity formed by breaking apart of the cells; *i*, soft bast, a form of sieve tissue; *p*, thin-walled parenchyma. (Sachs.)

124. Rise of water in the vessels.—During the movement of the water or nutrient solutions upward in the stem the vessels of the wood portion of the bundle in certain plants are nearly or quite filled, if root pressure is active and transpiration is not very rapid. If, however, on dry days transpiration is in excess of root pressure, as often happens, the vessels are not filled with the water, but are partly filled with certain gases because the air or other gases in the plant become rarefied as a result of the excessive loss of water. There are then successive rows of air or gas bubbles in the vessels separated by films of water which also line the walls of the vessels. The condition of the vessel is much like that of a glass tube through which one might pass the "froth" which is formed on the surface of soapy water. This forms a chain of bubbles in the vessels. This chain has been called Jamin's chain because of the discoverer.

125. Rise of water in the bundles is not well understood.—Why water or food solutions can be raised by the plant to the height attained by some trees has never been satisfactorily explained. There are several theories pro-

pounded which cannot be discussed here. It is probably a very complex process. Root pressure and transpiration both play a part, or at least can be shown, as we have seen, to be capable of lifting water to a considerable height.

126. Synopsis of tissues.

- Epidermal system.
  - Epidermis.
  - Trichomes (hairs).
    - Simple hairs.
    - Many-celled hairs.
    - Branched hairs, often stellate.
    - Clustered, tufted hairs.
    - Glandular hairs.
    - Root hairs.
  - Guard cells of stomates.
- Fibrovascular system.
  - Xylem.
    - Spiral vessels.
    - Pitted vessels.
    - Scalariform vessels.
    - Annular vessels.
    - Wood fibres.
    - Wood parenchyma.
  - Cambium (fascicular).
  - Phloem.
    - Sieve tubes.
    - Bast fibres.
    - Bast parenchyma.
- Fundamental system.
  - Cork.
  - Parenchyma.
    - Ground tissue.
    - Interfascicular cambium.
    - Medullary rays.
  - Bundle sheath.
  - Sclerenchyma (thick-walled cells, in nuts, etc.). Collenchyma (thick-angled cells, under epidermis of succulent stems).

Demonstration 22.*

127. If it is desired that the pupils examine under the microscope the different elements of the epidermal and fundamental system, the teacher can make or procure sections to illustrate them. The pupils can then study and make sketches to illustrate the structures.

Material.—Leaves of stored celery, the older ones with rather tough petioles, and considerable leaf surface; or caladium leaves with long petiole

* This demonstration may well be omitted.

from the conservatory; old dead corn-stalks. Shoots of the garden balsam (impatiens) are good.

A solution of fuchsin (add a few crystals to water), or use red ink.

For study of the vascular bundles, sections may be made of the stems or petioles of the same plants, or of fresh corn stalks, of the stem of the sunflower, or castor-oil bean. The teacher can make these sections either free hand, or with a microtome; or if preferred, permanent slides to illustrate the structure of the vascular bundles may be obtained.

If the pupils are to make their own sections for study, sharp razors will also be required.

Microscope, etc., for demonstration 21.

CHAPTER XII.

HOW PLANTS GET THEIR CARBON FOOD.

I. THE GASES CONCERNED.

Exercise 26.

128. Gas given off by green plants in the sunlight.—Take some green alga, like spirogyra or vaucheria, which is in a fresh condition, place one lot in a beaker or tall glass vessel of water and set this in the direct sunlight or in a well lighted place. At the same time cover a similar vessel of spirogyra with black cloth so that it will be in the dark, or at least in very weak light.

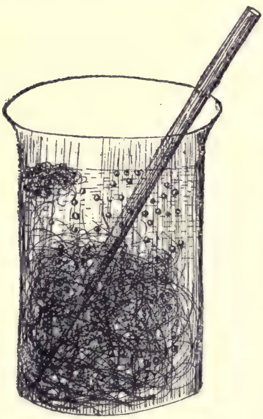

Fig. 55.
Oxygen gas given off by spirogyra.

129. The gas is shown in the form of bubbles.—In a short time we that in the first vessel small bubbles of gas are accumulating on the surface of the threads of the spirogyra, and now and then some free themselves and rise to the surface of the water. Where there is quite a tangle of the threads the gas is apt to become caught and held back in larger bubbles, which on agitation of the vessel are freed.

Examine the vessel which was covered to exclude the light, or which was placed in the dark. Are bubbles of gas given off here? Place the vessel in the light and note how soon bubbles begin to pass off.

Exercise 27.

130. Experiment with elodea.—Take one of the higher green plants, an aquatic plant like elodea, callitriche, etc. Place the plant in the water with the cut end of the stem uppermost, but still immersed, the plant being weighed down by a glass rod or other suitable object. If we place the vessel of water

containing these leafy stems in the bright sunlight, in a short time bubbles of gas will pass off quite rapidly from the cut end of the stem.

In the stem from which the leaves have been cut are there as many bubbles? What is the reason? What part of the leafy shoot gives rise to the greater part of the gas?

Demonstration 23.

131. To determine the kind of gas given off by green plants in the sunlight.—Take quite a quantity of the plants of elodea and place them under an inverted funnel which is immersed in water: the gas will be given off in quite large quantities and will rise into the narrow exit of the funnel. The funnel should be one with a short tube, or the vessel one which is quite deep so that a small test tube which is filled with water may in this condition be inverted over the opening of the funnel tube. Place in the bright sunlight for several days.

With this arrangement of the experiment the gas will rise in the inverted test tube, slowly displace a portion of the water, and become collected in a sufficient quantity to afford us a test. When a considerable quantity has accumulated in the test tube, we may close the end of the tube in the water with the thumb, lift it from the water and invert. The gas will rise against the thumb. A dry soft pine splinter should be then lighted, and after it has burned a short time, extinguish the flame by blowing upon it, when the still burning end of the splinter should be brought into the mouth of the tube as the thumb is quickly moved to one side. The glowing of the splinter shows that the gas is *oxygen.*

Fig. 56.
Bubbles of oxygen gas given off from elodea in presence of sunlight. (Oels)

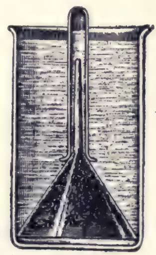

Fig. 57.
Apparatus for collecting quantity of oxygen from elodea. (Detmer.)

132. Oxygen given off by green land plants also.—If we should extend our experiments to land plants we should find that oxygen is given off by them under these conditions of light. Land plants, however, will not do this when they are immersed in water, but it is necessary to set up rather complicated apparatus and to make analyses of the gases at the beginning and at the close of the experiments. This has been done, however, in a sufficiently large number of cases so that we know that all green plants in the sunlight, if temperature and other conditions are favorable, give off oxygen.

133. Absorption of carbon dioxide. — We have next to inquire where the oxygen comes from which is given off by green plants when exposed to the sunlight, and also to learn something more of the conditions necessary for the process. We know that water which has been for some time exposed to the air and soil, and has been agitated, like running water of streams, or the water of springs, has mixed with it a considerable quantity of oxygen and carbon dioxide.

Demonstration 24.

134. To show the result in boiled water.—Boil spring water or hydrant water which comes from a stream containing oxygen and carbon dioxide, for about 20 minutes, to drive off these gases. Set this aside where it will not be agitated, until it has cooled sufficiently to receive plants without injury. Now place some spirogyra or vaucheria, and elodea, or other green water plant, in this boiled water and set the vessel in the bright sunlight under the same conditions which were employed in the experiments for the evolution of oxygen. No oxygen is given off.

NOTE.—It can be demonstrated that carbon dioxide is absorbed by the plant while the oxygen is passing off. In the case of aquatic plants the carbon dioxide is mixed with the water, while in the case of the land plants the carbon dioxide comes from the air. In the study of respiration we shall find that carbon dioxide is formed within the plant. Some of the carbon dioxide then which plants use when they are giving off oxygen comes from within the plant itself. For some simple experiments to demonstrate the absorption of carbon dioxide during this process see paragraphs 119–124 of the author's larger "Elementary Botany."

135. A chemical change of the gas takes place within the plant cell.—Since oxygen is given off while carbon dioxide, a different gas, is necessary, it would seem that a chemical change takes place in the gases within the plant. Since the process takes place in such simple plants as spirogyra as well as in the more bulky and higher plants, it appears that the changes go on within the cell, in fact within the protoplasm. We should remember also that this chemical change of the gases in plants can only take place in the presence of light.

Synopsis.—At temperatures suitable for growth, green plants in the sunlight are constantly giving off a gas.

In the case of water plants this gas can be seen in the form of bubbles.

This gas is *oxygen.*

At the same time that oxygen is being given off by green plants carbon dioxide (carbon and oxygen) is being absorbed by the plant.

A chemical change in the carbon dioxide takes place in the plant and some of the oxygen is thus liberated.

Material.—Fresh mats of some alga, either spirogyra, zygnema, or vaucheria.

Fresh shoots of one of the higher water plants like elodea (found in the shallow water of ponds, lakes, or streams near low ground).

Beakers with fresh spring or hydrant water to hold the plants. A funnel and large test tube for demonstration 23. The demonstration should be started several days in advance.

CHAPTER XIII.

HOW PLANTS GET THEIR CARBON FOOD.

Concluded.

II. Starch formed by Green Plants.

Exercise 28.

136. To test for the presence of starch in green leaves.—Take green leaves which have been for several hours in the bright sunlight. Boil them in alcohol, using great care not to set the alcohol on fire. This removes the chlorophyll. If it is desired not to use the alcohol, boil the leaves in water for a short time. Then place them in alcohol, changing the alcohol occasionally. The green color is extracted slowly by this process. It may be extracted more rapidly if the preparation is placed in the sunlight. When the leaves are decolorized, place them in a solution of iodine in potassium iodide. In place of this solution, a tincture of iodine purchased at drugstores answers fairly well. Observe the color of the leaves. This color is due to the presence of starch, the starch becoming dark blue or nearly black when treated with iodine.

137. Starch is formed only in the green parts of variegated leaves.—If we test for starch in variegated leaves like the leaf of a coleus plant, we shall have an interesting demonstration of the fact that the green parts of plants only form starch. We may take a leaf which is partly green and partly white, from a plant which has been standing for some time in bright light. Fig. 58 is from a photograph of such a leaf. We should first boil it in alcohol to remove the green color. Now immerse it in the potassium iodide of iodine solution for a short time. The parts which were formerly green are now dark blue or nearly black, showing the presence of starch in those portions

of the leaf, while the white part of the leaf is still uncolored. This is well shown in fig. 59, which is from a photograph of another coleus leaf treated with the iodine solution.

138. Green parts of plants form starch when exposed to light.—Thus we find that in the case of all the green plants we

Fig. 58.
Leaf of coleus showing green and white areas, before treatment with iodine.

Fig. 59.
Similar leaf treated with iodine, the starch reaction only showing where the leaf was green.

have examined, starch is present in the green cells of those which have been standing for some time in the sunlight where the process of the absorption of CO_2 and the giving off of oxygen can go on, and that in the case of plants grown in the dark, or in leaves of plants which have stood for some time in the dark, starch is absent. We reason from this that starch is the product of the chemical change which takes place in the green cells under these conditions. Because CO_2 is absorbed during this process, and because of the chemical changes which take place in the formation of starch, by means of which the carbon

is changed from its attraction in the molecule of carbon dioxide to its attraction in the molecule of starch, the process has been termed carbon assimilation. But since it is not truly an assimilatory process, and because sunlight is necessary in the first step of the conversion, it has also been recently termed *photosyntax* or *photosynthesis*. These terms, however, seem inappropriate, since the *synthetic* part of the process is not known to be due to the action of light. In the presence of chlorophyll light reduces the carbon dioxide, while the synthetic part of the process may not be influenced by light. For popular treatment the term *carbon conversion* was proposed in the author's larger "Elementary Botany." But this is also an unfortunate term, and he would now propose the simple term, *starch formation*. But there should be no objection to the use of the term carbon assimilation, or photosynthesis.

139. Fungi cannot form starch.—If we should extend our experiments to the fungi, which lack the green color so characteristic of the majority of plants, we should find that starch formation does not take place even though the plants are exposed to direct sunlight. These plants then obtain carbohydrates for food from other sources, as parasites from living plants, and as saprophytes from dead plants, or from certain plant products.

III. Chlorophyll and Chlorophyll Bodies.

140. Form of the chlorophyll bodies.—This green substance of plants, the presence of which is necessary in the formation of starch, is chlorophyll. It usually occurs in definite bodies, the chlorophyll bodies. Chlorophyll bodies vary in form in some different plants, especially in some of the lower plants. This we have already seen in the case of spirogyra, where the chlorophyll body is in the form of a very irregular band, which courses around the inner side of the cell wall in a spiral manner. In zygnema, which is related to spirogyra, the chlorophyll bodies are star-shaped. In the desmids the form varies greatly.

In vaucheria, a branched thread-like alga, the chlorophyll bodies are oval in outline. This form of the chlorophyll body is that which is common to many of the green algæ, and also occurs in the mosses, liverworts, ferns, and the higher plants. It is a more or less rounded, oval, flattened body.

Demonstration 25.

141. Chlorophyll bodies in leaves.—If it is desired to demonstrate the chlorophyll bodies the teacher can make free-hand sections from fresh leaves of a begonia, or from some other plant. In figure 60 are shown the chlorophyll bodies in the leaf of the ivy.

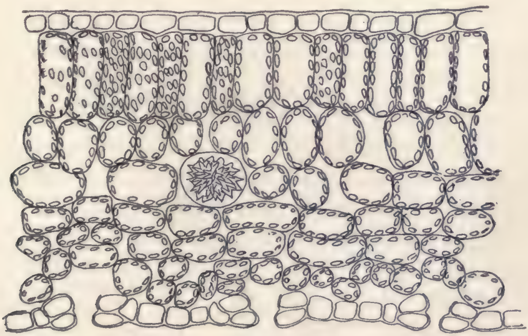

Fig. 60.
Section of ivy leaf, palisade cells above, loose parenchyma, with large intercellular spaces in centre. Epidermal cells on either edge, with no chlorophyll bodies.

142. Chlorophyll.—The chlorophyll is a coloring substance which resides in the chlorophyll body. It can be extracted from the body by the use of alcohol. The body is a plastid of a proteid nature, widely distributed in many plants. The plastid when not exposed to light is usually colorless, when exposed to light it often becomes green; while in the roots of the carrot and in the petals of some flowers it possesses other colors. When it is colorless it is called a *leucoplast*, when green a *chloroplast*, and when yellow, red, etc., a *chromoplast*.

143. Where starch is first formed.—The starch is first formed in the chlorophyll bodies. The chlorophyll absorbs

certain of the rays of light. The absorbed light is transformed into energy which assists in the chemical changes taking place in the carbonic acid (when the carbon dioxide of the air meets the water in the cell it forms carbonic acid) in the cell by which starch is built up. By mounting leaves of some mosses, or the prothallia of ferns in water, for microscopic examination, the starch grains can be seen within the chlorophyll bodies. They can often be seen in the chlorophyll bodies in the leaf of begonias when thin sections are made for observation under the microscope.

144. Starch in other parts of plants than the leaves.—While the larger part of the starch is formed in the green leaves, it is often found stored in large quantities in parts of plants not exposed to the light. It is formed in the leaves during the day, and at night it is dissolved and transported to other parts of the plant where it may be needed for the manufacture of other substances used in plant growth, or it may be stored in special receptacles in the form of starch grains again, as in the potato tuber, the roots of the sweet potato, or in the thick leaves of the onion, etc.

Exercise 29.

145. To test for the presence of starch in parts of the plant where it is stored.—Cut a potato tuber, scrape some of the potato at the cut surface into a pulp. Apply a small quantity of a solution of iodine to this pulp. Describe the result. The color produced is the reaction for what substance? Where was the starch first formed in the potato plant? How is it that later it is found in the tubers which are underground stems? What function for the potato plant does this stored starch serve?

If it is desired the pupils may test for starch in the enlarged roots of the sweet potato, the grains of corn, or in the leaves of the onion.

Place a small quantity of corn starch (as much as will be lifted on the point of a small knife blade) in a test tube. Add water to the depth of two inches and warm over a flame, then cool by moving the end in cold water or by holding it under the water tap. Add to the starch water a drop or two of a tincture of iodine (iodine crystals dissolved in alcohol). Observe the blue color. Now heat over the flame; the color disappears because the warm water extracts the iodine from the starch grains. Now cool again. The blue color reappears since the starch again takes up the iodine.

Demonstration 26.

146. Form of starch grains.—Where starch is stored as a reserve material it occurs in grains which usually have certain characters peculiar to the species of plant in which they are found. They vary in size in many different plants, and to some extent in form also. Scrape some of the cut surface of the potato tuber into a pulp and mount a small quantity in water, or make a thin section for microscopic examination. We find large starch grains of a beautiful structure. The grains are oval in form and more or less irregular in outline. But the striking peculiarity is the presence of what seem to be alternating dark and light lines in the starch grain. The lines form irregular rings, which are smaller and smaller until we come to the small central spot termed the "hilum" of the starch grain. It is supposed that these apparent lines in the starch grain are caused by the starch substance being deposited in alternating dense and dilute layers, the dilute layers containing more water than the dense ones; others think that the successive layers from the hilum outward are regularly of diminishing density, and that this gives the appearance of alternating lines.

147. Necessity of carbon food for plants. — The starch formed by plants is one of the organic substances manufactured by plants. It is the basis for the formation of other organic substances. Starch contains carbon, hydrogen, and oxygen, in the proportion of 6 molecules of carbon, 10 molecules of hydrogen, and 5 molecules of oxygen ($C_6H_{10}O_5$). The water in the starch is in the proportion of 2 molecules of hydrogen to 1 molecule of oxygen (H_2O). For this reason it is called a *carbohydrate*. The most important carbohydrates in plants are starch, the sugars, and cellulose, the latter substance, or modifications of it, forming the cell walls of plants. Without carbon-food green plants cannot make any appreciable increase in plant substance, though a considerable increase in size of the plant may take place (see paragraph 194). Chlorophylless plants, like the fungi and certain parasitic or saprophytic (as the Indian-pipe, certain of the orchids, etc.) angiosperms, derive their carbon-food from the carbohydrates manufactured by the green plants. Animals also derive their carbohydrates through the medium of the green plants, either directly or indirectly.

NOTE.—For further experiments and discussion of this subject see the author's larger "Elementary Botany."

Synopsis.

Starch formation, by green plants.	Carbon dioxide is absorbed by the green parts of plants. In the presence of chlorophyll in the cell, and under the influence of sunlight, a chemical change takes place in the carbonic acid (carbon dioxide united with the water in the plant-cell). As a result of this chemical change starch is formed by the union of carbon, hydrogen, and oxygen ; but all of the oxygen brought in by the carbon dioxide is not needed in the manufacture of starch. This portion of the oxygen is set free.

Fungi, or other plants which lack chlorophyll cannot form starch.

Parts of leaves, or parts of plants, which lack chlorophyll cannot form starch.

Chlorophyll is the green pigment in the chlorophyll bodies (chloroplasts).

Starch is first formed in the chlorophyll bodies, and then dissolved and carried to other parts of the plant, for food, or to be stored.

Material.—Fresh leaves of ordinary plants which have been for a few hours in daylight (some of the seedlings which have been grown, or plants from the greenhouse will answer); some variegated leaves of the coleus plant if possible.

For study of chlorophyll, leaves of begonia to section are good. For study of starch, potato tubers ; and if other objects are wanted, sweet potatoes, onions, etc.

If the pupils make their own sections of the begonia leaves, sharp razors will be necessary.

Chemicals needed in the test for starch : a solution of iodine in potassium iodide (see appendix for formula), or an ordinary tincture of iodine obtained at drugstores ; alcohol.

Microscope, etc., if it is desired to demonstrate the structure of starch grain.

CHAPTER XIV.

ROUGH ANALYSIS OF PLANT SUBSTANCE.

148. Some simple experiments to indicate the nature of plant substance.—After these building-up processes of the plant, it is instructive to perform some simple experiments which indicate roughly the nature of the plant substance, and serve to show how it can be separated into other substances, some of them being reduced to the form in which they existed when the plant took them as food. For exact experiments and results it would be necessary to make chemical analyses.

Exercise 30.

149. The water in the plant.—Take fresh leaves or leafy shoots or other fresh plant parts. Weigh. Permit them to remain in a dry room until they are what we call "dry." Now weigh. The plants have lost weight, and from what we have learned in studies of transpiration this loss in weight we know to result from the loss of water from the plant.

Exercise 31.

150. The dry plant material contains water.—Take dry leaves, shavings, or other dry parts of plants. Place them in a test-tube. With a holder rest the tube in a nearly horizontal position, with the bottom of the tube in the flame of a bunsen burner. Very soon, before the plant parts begin to "burn," note that moisture is accumulating on the inner surface of the test-tube. This is water driven off which could not escape by drying in air, without the addition of artificial heat, and is called "hygroscopic water."

151. Water formed on burning the dry plant material.—Light a soft-pine or bass-wood splinter. Hold a thistle tube in one hand with the bulb downward and above the flame of the splinter. Carbon will be deposited over the inner surface of the bulb. After a time hold the tube toward the window and look through it above the carbon. Drops of water have accumulated on

on the inside of the tube. This water is formed by the rearrangement of some of the hydrogen and oxygen, which is set free by the burning of the plant material, where they were combined with carbon, as in the cellulose, and with other elements.

Exercise 32.

152. Formation of charcoal by burning.—Take dried leaves, and shavings from some soft wood. Place in a porcelain crucible, and cover about 3*cm* deep with dry fine earth. Place the crucible in the flame of a Bunsen burner and let it remain for about 15 minutes. Remove and empty the contents. If the flame was hot the plant material will be reduced to a good quality of charcoal. The charcoal consists largely of carbon.

153. The ash of the plant.—Place in the porcelain crucible dried leaves and shavings as before. Do not cover with earth. Place the crucible in the flame of the Bunsen burner, and for a moment place on the porcelain cover; then remove the cover, and note the moisture on the under surface from the escaping water. Permit the plant material to burn; it may even flame for a time. In the course of 15 minutes it is reduced to a whitish powder, much smaller in bulk than the charcoal in the former experiment. This is the ash of the plant.

What has become of the carbon? In this experiment the air was not excluded from the plant material, so that oxygen combined with the carbon as the water was freed, and formed carbon dioxide, passing off into the air in this form. This it will be remembered is the form in which the plant took the carbon-food in through the leaves. Here the carbon dioxide met the water coming from the soil, and the two united to form, ultimately, starch, cellulose, and other compounds of carbon; while with the addition of nitrogen, sulphur, etc., coming also from the soil, still other plant substances were formed.

NOTE.—The ash of the plant contains, usually, potash, soda, lime, magnesium, ferric oxide, phosphoric acid, sulphuric acid, silica, chlorine. (See page 64 of the author's larger "Elementary Botany," 2d Ed., revised.)

Synopsis.

The living plant contains a large amount of water.

When the plant is dried in the air it still contains a considerable amount of water.

This water of air-dried plants can only be driven off by artificial heat (at a temperature of 100° F. for some time).

When all of the water is dried out of the plant, if the plant is burned so that the plant substance is disorganized, several different substances are formed.

1. Water is formed by the uniting of hydrogen and oxygen as these elements are freed from the plant substance by the burning.
2. Certain gases, one of them is carbon dioxide, formed by the carbon from the disorganized plant substance uniting with oxygen of the air during the burning.

If the dried plant material is burned while oxygen from the air is excluded, the carbon cannot unite with oxygen to form carbon dioxide, but remains in the form of charcoal, which is almost pure carbon.

When plant material is burned with access of oxygen the residuum is a whitish-gray powder called the *ash.* (See page 64 of the author's larger "Elementary Botany," 2d Ed., revised.)

Material.—Leafy shoots fresh; air-dried leaves, and some soft dry wood (white pine wood, bass wood, or some similar soft wood).

Apparatus.—Bunsen burner to supply gas-flame; small porcelain crucibles with covers; supports to hold crucibles in the flame; test tubes; thistle tubes; some dry earth.

CHAPTER XV.

SOME OTHER WAYS IN WHICH CERTAIN PLANTS OBTAIN FOOD.

(This chapter is for reading, or the teacher may make demonstrations before the class if there is time.)

154. Nutrition of moulds.—Start some growths of the black mould as described in paragraph 49. Then for several days observe the growth. First there appear small spots of delicate white threads. This tuft of threads increases in size, the threads elongate and branch. Finally upright threads appear which bear the black heads (sporangia, sing. sporangium) and spores again. Break the potatoes open through several of these tufts. The threads of the mould enter the potato also. The mycelium in the potato or in the bread absorbs food solutions from these substances in the same way that root hairs absorb food solutions. The potato and the bread are largely made up of starch from green plants. This demonstration serves excellently to show how the fungi which lack chlorophyll obtain their carbohydrate food from the products of green plants (see paragraph 147).

155. Nutrition of the larger fungi.—If we select some one of the larger fungi, the majority of which belong to the mushroom family and its relatives, which is growing on a decaying log or in the soil, we shall see on tearing open the log, or on removing the bark or part of the soil, as the case may be, that the stem of the plant, if it have one, is connected with whitish strands. During the spring, summer, or autumn months, examples of the mushrooms connected with these strands may usually be found readily in the fields or woods, but during the

winter and colder parts of the year often they may be seen in forcing houses, especially those cellars devoted to the propagation of the mushroom of commerce.

156. The fungus strands.—These strands are made up of numerous threads of the mycelium which are closely twisted and interwoven into a cord or strand, which is called a mycelium strand, or *rhizomorph.* These are well shown in fig. 61, which is from a photograph of the mycelium strands, or "spawn" as the grower of mushrooms calls it, of Agaricus campestris. The little knobs or enlargements on the strands are the young fruit bodies, or "buttons."

157. Mats of mycelium are sometimes very extensive.—While these threads or strands of the mycelium in the decaying wood or in the decaying organic matter of the soil are not true roots, they function as roots, or root hairs, in the absorption of food materials. In old cellars and on damp soil in moist places we sometimes see fine examples of this vegetative part of the fungi, the mycelium. But most magnificent examples are to be seen in abandoned mines where timber has been taken down into the tunnels far below the surface of the ground to support the rock roof above the mining operations. I have visited some of the coal mines at Wilkesbarre, Pa., and here on the wood props and doors, several hundred feet below the surface, and in blackest darkness, in an atmosphere almost completely saturated at all times, the mycelium of some of the wood-destroying fungi grows in a profusion and magnificence which is almost beyond belief.

158. Form of the mushroom.—A good example for this study is the common mushroom (Agaricus campestris).

This occurs from July to November in lawns and grassy fields. The plant is somewhat umbrella-shaped, as shown in fig. 62, and possesses a cylindrical stem attached to the under side of the convex cap or pileus. On the under side of the pileus are thin radiating plates, shaped somewhat like a knife blade. These are the gills, or lamellæ, and toward the stem they are

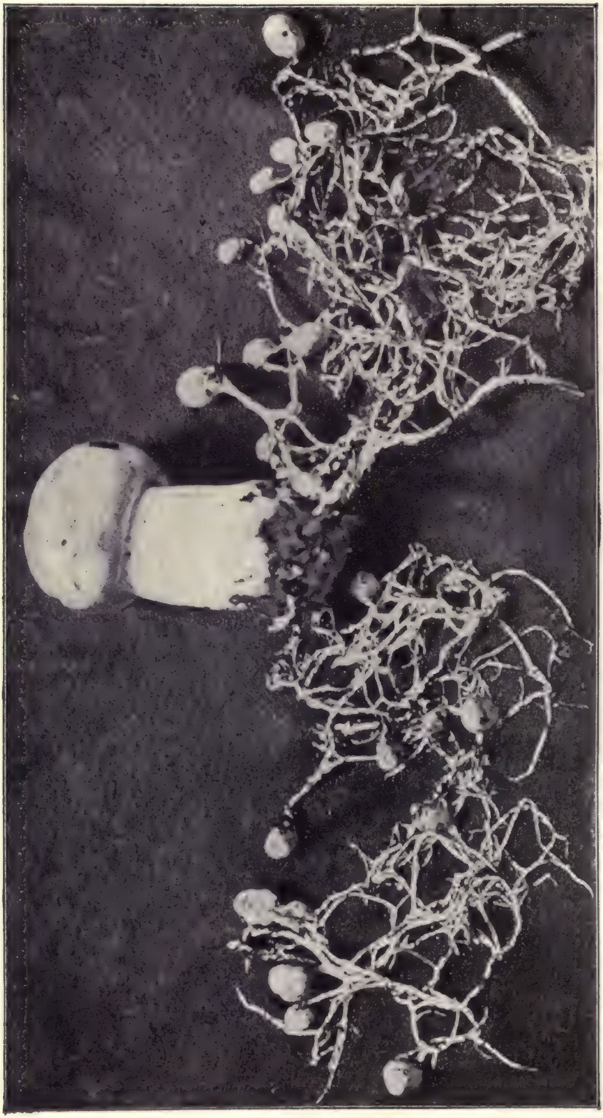

Fig. 61.
Agaricus campestris. Soil washed from "spawn" and "buttons," showing the minute young "buttons" attached to the strands of mycelium.

rounded on the lower angle and are not attached to the stem. The longer ones extend from near the stem to the margin of the pileus, and the V-shaped spaces between them are occupied by successively shorter ones. Around the stem a little below the gills is a collar, termed the ring or annulus.

Fig. 62.
Agaricus campestris. View of under side showing stem, annulus, gills, and margin of pileus.

159. Nutrition of parasitic fungi.—Certain of the fungi grow on or within the higher plants and derive their food materials from them and at their expense. Such a fungus is called a *parasite,* and there are a large number of these plants, which are known as *parasitic fungi.* The plant at whose expense they grow is called the "*host.*"

One of these parasitic fungi, which it is quite easy to obtain in greenhouses or conservatories during the autumn and winter, is the carnation rust (*Uromyces caryophyllinus*), since it breaks out in rusty dark brown patches on the leaves and stems of the carnation (see fig. 63). If we make thin cross-sections through one of these spots on a leaf, and place them for a few minutes in a solution of chloral hydrate, portions of the tissues of the

leaf will be dissolved. After a few minutes we wash the sections in water on a glass slip, and stain them with a solution of eosin. If the sections were carefully made, and thin, the threads of the mycelium will be seen coursing between the cells of the leaf as slender threads. Here and there will be seen short branches of these threads which penetrate the cell wall of the host and project into the interior of the cell in the form of an irregular knob. Such a branch is a *haustorium*. By means of this haustorium, which is here only a short branch of the mycelium, nutritive substances are taken by the fungus from the protoplasm or cell-sap of the carnation. From here it passes to the threads of the mycelium. These in turn supply food material for the development of the dark brown gonidia, which we see form the dark-looking powder on the spots. Many other fungi form haustoria, which take up nutrient matters in the way described for the carnation rust.

Fig. 63.
Carnation rust on leaf and flower stem. From photograph.

160. Nutrition of the dodder.—The dodder (cuscuta) is an example of one of the higher plants that is parasitic. The stem twines around the stems of other plants, sending short conical processes termed haustoria in their tissues. By means of these the nutriment is absorbed from the host. The means of absorb-

ing nutriment may be demonstrated by making sections through both parasite and host at a point where the haustoria enter the stem. These should then be mounted for examination with the microscope.

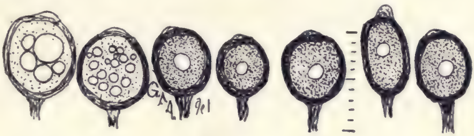

Fig. 64.
Several teleutospores, showing the variations in form.

161. Carnivorous plants, or insectivorous plants.—Examples of these are the well-known Venus fly-trap (Dionæa muscipula) and the sundew (Drosera rotundifolia). These are illustrated in figures 67 and 68. The lamina of the leaf of the Venus

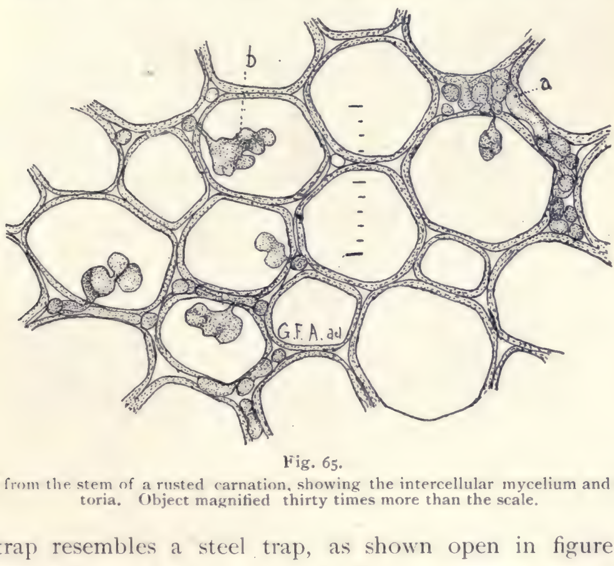

Fig. 65.
Cells from the stem of a rusted carnation, showing the intercellular mycelium and haustoria. Object magnified thirty times more than the scale.

fly-trap resembles a steel trap, as shown open in figure 67. When an insect alights on the leaf and touches one of the hairs (there are three prominent hairs on the upper surface of each

half of the leaf), the leaf suddenly closes and captures it. It has been found that when the hair is touched the first time no movement of the leaf takes place, but when it is touched the second time the leaves close up suddenly. There are small glands on the surface of the leaf which excrete a substance that digests the insect, when the digested portions are absorbed by the leaf and are assimilated by the plant as food. The leaf of the sundew is quite different in form and action. In the species

Fig. 66.
Dodder.

illustrated here the lamina of the leaf is rotund, and the upper surface is covered with numerous long glandular hairs. The gland is on the end of the hair, and a sticky substance is

excreted by the cells of the gland, which glistening in the sunlight reminds one of drops of dew. For this reason the plant is called the sundew. When an insect alights on a leaf the viscid substance clings to it and holds it firmly so that it cannot escape. The glandular hairs then begin slowly to curve inward toward the centre of the leaf as shown in figure 68. Finally the margins of the leaf become inrolled also, so that the insect is held fast and close to the upper surface of the leaf. Excretions from the leaf surface act as a digestive ferment upon the insect.

162. Nutrition of bacteria.—Bacteria are very minute plants, in the form of short rods, which are either straight or spiral, while some are minute spheres. They are widely distributed; some cause diseases of plants and animals, others cause decay of organic matter, while still others play an important rôle in converting certain nitrogen compounds into an available form for plant food. They absorb their food through the surface of their body. They may be obtained in abundance for study in infusions of plants or of meats.

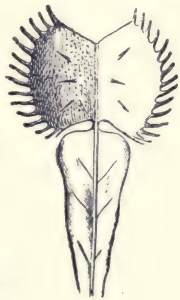

Fig. 67.

Leaf of Venus fly-trap (Dionæa muscipula), showing winged petiole and toothed lobes.

Fig. 68.

Leaf of Drosera rotundifolia, some of the glandular hairs folding inward as a result of a stimulus.

To demonstrate bacteria in infusions take a small quantity of hay or of meat. Place it in water and heat at about 60° C. for an hour. Then set the vessel containing the infusion aside in a warm room for several days. Numbers of bacteria will be developed, some of them probably motile. With a good microscope they may be demonstrated by mounting a drop of the infusion on a glass slip and preparing for examination with the microscope

Nitrogen gatherers.

163. How clovers, peas, and other legumes gather nitrogen.—It has long been known that clover plants, peas, beans, and many other leguminous plants are often able to thrive in soil where the cereals do but poorly. Soil poor in nitrogenous plant food becomes richer in this substance where clovers, peas, etc., are grown, and they are often planted for the purpose of enriching the soil. Leguminous plants, especially in poor soil, are almost certain to have enlargements, in the form of nodules, or "root tubercles." A root of the common vetch with some of these root tubercles is shown in fig. 69.

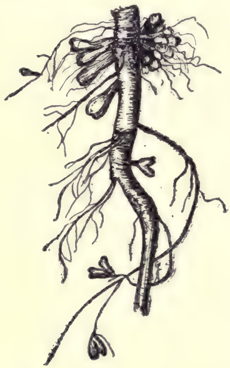

Fig. 69.
Root of the common vetch, showing root tubercles.

163a. A fungal or bacterial organism in these root tubercles.—If we cut one of these root tubercles open, and mount a small portion of the interior in water for examination with the microscope, we shall find small rod-shaped bodies, some of which resemble bacteria, while others are more or less forked into forms like the letter Y, as shown in fig. 70. These bodies are rich in nitrogenous substances, or proteids. They are portions of a minute organism, of a fungous or bacterial nature, which attacks the roots of leguminous plants and causes these nodular outgrowths. The organism (Phytomyxa leguminosarum) exists in the soil and is widely distributed where legumes grow.

164. How the organism gets into the roots of the legumes.—This minute organism in the soil makes its way through the wall of a root hair near the end. It then grows down the interior of the root hair in the form of a thread. When it reaches the cell walls it makes a minute perforation, through which it grows to enter the adjacent cell, when it enlarges again. In this way it passes from the root hair to the cells of

the root and down to near the centre of the root. As soon as it begins to enter the cells of the root it stimulates the cells of that portion to greater activity. So the root here develops a large lateral nodule, or "root tubercle." As this "root

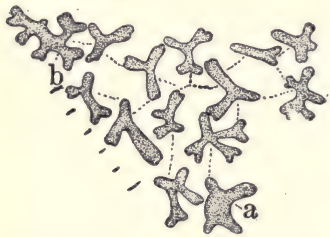

Fig. 70
Root-tubercle organism from vetch, old condition.

Fig. 71.
Root-tubercle organism from Medicago denticulata.

tubercle" increases in size, the fungus threads branch in all directions, entering many cells. The threads are very irregular in form, and from certain enlargements it appears that the rod-like bodies are formed, or the thread later breaks into myriads of these small "bacteroids."

165. The root organism assimilates free nitrogen for its host.—This organism assimilates the free nitrogen from the air in the soil, to make the proteid substance which is found stored in the bacteroids in large quantities. Some of the bacteroids, rich in proteids, are dissolved, and the proteid substance is made use of by the clover or pea, as the case may be. This is why such plants can thrive in soil with a poor nitrogen content. Later in the season some of the root tubercles die and decay. In this way some of the proteid substance is set free in the soil. The soil thus becomes richer in nitrogenous plant food.

The forms of the bacteroids vary. In some of the clovers they are oval, in vetch they are rod-like or forked, and other forms occur in some of the other genera.

CHAPTER XVI.

RESPIRATION.

Exercise 33.

166. Simple experiment to demonstrate the evolution of CO_2 during germination.—Where there are a number of students and a number of large cylinders are not at hand, take bottles of a pint capacity, place in the bottom some peas soaked for 12 to 24 hours. Cover with a glass plate which has been smeared with vaseline to make a tight joint with the mouth of the bottle. Set aside in a moderately warm place for 24 hours. Then slide the glass plate a little to one side and quickly pour in a little baryta water so that it will run down on the inside of the bottle. Cover the bottle again. Note the precipitate of barium carbonate which demonstrates the presence of CO_2 in the bottle. Lower a lighted taper. It is extinguished because of the great quantity of CO_2.

Fig. 72.
Test for presence of carbon dioxide in vessel with germinating peas. (Sachs.)

Exercise 34.

167. Comparison of respiration in plants and animals.—Take some of the baryta water and breathe upon it. The same film is formed. The carbon dioxide which we exhale is absorbed by the baryta water and forms barium carbonate, just as in the case of the peas. In the case of animals the process by which oxygen is taken into the body and carbon dioxide is given off is *respiration.* The process in plants which we are now studying is the same, and also is respiration. The oxygen in the vessel was partly used up in the process and carbon dioxide was given off. (It will be seen that this process is exactly the opposite of that which takes place in starch formation.)

Exercise 35 (or Demonstration).

168. Respiration is necessary for growth.—After we have performed the experiment in paragraph 166, if the vessel has not been open too long so

that oxygen has entered, we may use the vessel for another experiment, or set up a new one to be used in the course of 12 to 24 hours, after the oxygen has been consumed. Place some folded damp filter paper on the germinating peas in the jar. Upon this place one-half dozen peas which have just been germinated, and in which the roots are about 20–25*mm* long. See figures 73, 74. The vessel should be covered tightly again and set aside in a

Fig. 73. Fig. 74.

Fig. 74*a*. Fig. 73*a*.

Fig. 73.—Seedlings in vessels containing an excess of carbon dioxide, and very little oxygen. No growth takes place.

Fig. 74.—Vessel with normal air used as a check. No excess of carbon dioxide, usual amount of oxygen. Normal growth takes place.

Figures 73*a* and 74*a* represent the condition of the peas in the experiment shown in figs. 73 and 74, a month later. The cylinders as set up for that experiment were left for a month and then photographed. The peas in the cylinder containing normal air have grown, producing stems which reach to the top of the cylinder, while in fig. 73*a*, where the oxygen was absent, the peas have died. At this time a test was made with a lighted taper; it burned brightly in the cylinder 74*a*, but was quickly extinguished in the cylinder 73*a*. The peas having died in this jar, decomposition had taken place and other gases than carbon dioxide were present, but there was not sufficient oxygen to support combustion.

warm room. A second jar with water in the bottom instead of the germinating peas should be set up as a check. Damp folded filter paper should be supported above the water, and on this should be placed one-half dozen peas with roots of the same length as those in the jar containing carbon dioxide.

169. Oxygen is necessary for growth.—In 24 hours examine and note how much growth has taken place. It will be seen that the roots have elongated but very little or none in the first jar, while in the second one we see that the roots have elongated considerably, if the experiment has been carried on carefully. Therefore in an atmosphere devoid of oxygen or an excess of carbon dioxide, very little growth will take place, which shows that normal respiration with access of oxygen is necessary for growth.

170. Energy set free during respiration.—From what we have learned of the exchange of gases during respiration we infer that the plant loses carbon during this process. If the process of respiration is of any benefit to the plant, there must be some gain in some direction to compensate the plant for the loss of carbon which takes place.

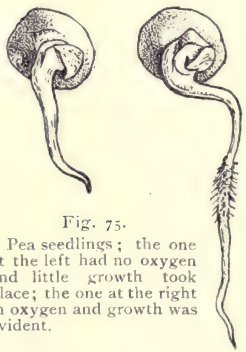

Fig. 75.
Pea seedlings; the one at the left had no oxygen and little growth took place; the one at the right in oxygen and growth was evident.

It can be shown by an experiment that during respiration there is a slight elevation of the temperature in the plant tissues. The plant then gains some heat during respiration. We have also seen in the attempt to grow seedlings in the absence of oxygen that very little growth takes place. But when oxygen is admitted growth takes place rapidly. The process of respiration, then, also sets free energy which is manifested in one direction, by growth.

Demonstration 27.

171. To set up the apparatus for demonstrating respiration.—Soak a double handful of peas for 12 to 24 hours in an abundance of cool water. Prepare a small quantity of baryta water, a saturated solution, and filter some into a short wide vial. Take a glass cylinder about 35*cm* high by 5*cm* in diameter. Select a perforated rubber cork to fit very tightly when crowded part way in the open end of the cylinder. Prepare a long S manometer by bending a glass tube which is about one and one-half meters long by 6*mm* inside diameter, into the form shown in figure 76. Put mercury into one end of the manometer as shown in the figure, and if it is desired to show the

experiment at a distance in the classroom, place a small quantity of a solution of eosin above each column of mercury. Insert the other end of the manometer through the preforation in the rubber cork. It must fit very tightly. If there is another perforation plug it with a glass rod. Take a wide-mouthed small glass jar—a small glycerine jelly jar is good—which will go inside the cylinder. Break a few sticks of caustic potash and drop in it. Nearly fill with water and tie a string around the top so that it can be lowered into the upper part of the cylinder without spilling any of the potash solution. Prepare a support for this by inserting a glass rod about 13*cm* long into a cork. Have all the parts of the apparatus and the material ready, and the baryta water in the open vial, so that the apparatus may be set up quickly. Have the cylinder warm and set the apparatus up in a room where the temperature is about 20° C. (about 68° Fahr.). Place a small quantity of damp paper (not wet) in the bottom of the cylinder. Place in the soaked peas to fill about 8*cm* to 10*cm*. Upon these place the small vial of baryta water. Drop in the support and press the glass rod down far enough so that the jar of potash solution will enter and pass far enough below the mouth of the cylinder to be out of the way of the rubber cork.

Insert the rubber cork containing the S manometer of mercury, placing between it and the side of the cylinder a stout needle to allow the escape of air while the cork is pressed in tightly. This allows the mercury to remain at the same level in both arms of the tube. Now remove the needle and set the apparatus aside where the temperature will remain at about 20° C., and let

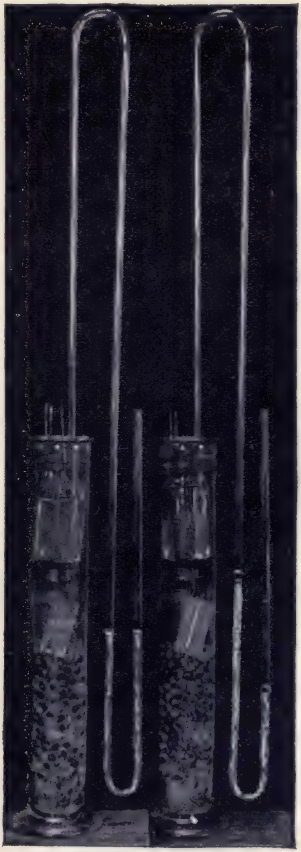

Fig. 76. Fig. 77.

Experiment to demonstrate respiraton.

Fig. 76.—At beginning of experiment; mercury in each arm equal. No oxygen has been consumed in vessel.

Fig. 77.—At close of experiment; mercury in inner arm has risen. Some oxygen has been consumed.

stand for about 24 hours. The apparatus should be set up quickly so that forming carbon dioxide will not displace the air.

172. Carbon dioxide given off during germination while oxygen from the air is consumed. — In a short while there can be seen a whitish film on the baryta water in the vial. In less than an hour this film may become so thick that with a little agitation it breaks and settles as a white precipitate. This white precipitate is barium carbonate. Some of the carbon dioxide given off by the peas is absorbed by the baryta water forming the insoluble barium carbonate. Carbon dioxide is also absorbed by the caustic potash solution in the bottom of the cylinder. Owing to the slowness with which the carbon dioxide diffuses from between the peas into the potash solution an excess may be formed. This excess of carbon dioxide in the cylinder produces a pressure which is shown by the rise of the mercury in the outer arm of the tube.*

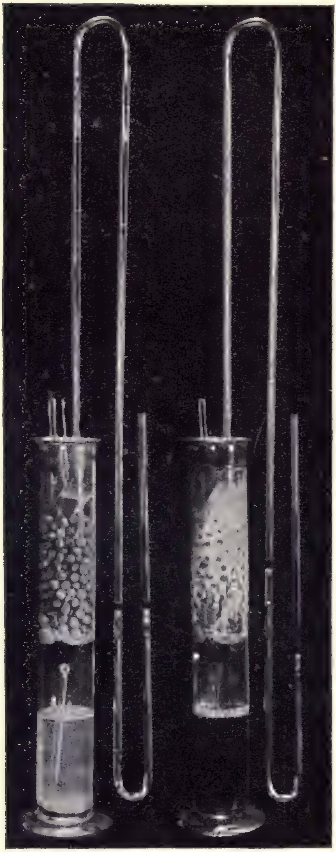

Fig. 78. Fig. 79.

Experiment to demonstrate respiration.

Fig. 78.—At beginning of experiment; mercury in each arm equal. No oxygen has been consumed in vessel.

Fig. 79.—At close of experiment; mercury in inner arm has risen. Some oxygen has been consumed.

In about 24 hours observe the experiment. If the mercury is still higher in the outer arm it shows that there is still

* When this inside pressure is produced it shows that more CO_2 is

an excess of CO_2 in the cylinder. At any rate lift the cylinder with the hands in such a way as to hold firmly at the same time the glass tube. Lift it up and down in such a way as to spill a portion of the baryta water over against the wall of the cylinder, and to dash the potash solution into a spray. Be careful not to toss the mercury out of either arm of the tube. If the open arm of the glass tube is closed with the finger (should the apparatus be set up as indicated in fig. 78), the cylinder may be inclined so as to let a portion of the potash solution run up among the peas to come directly in contact with the CO_2 remaining there. Now rest the cylinder on the table and observe the result. The mercury now, if it did not before, stands higher in the inner arm of the S tube, showing that some constituent of the air within the cylinder was consumed during the formation of the CO_2. This constituent of the air must be oxygen, since the carbon can only come from the plant. Where the baryta water was spilled over an abundance of the white precipitate of the barium carbonate is formed.

If desired the experiment can be set up as shown in figure 78, with the potash solution in the bottom of the cylinder, and the peas supported on a circular piece of wire netting held in place between two small corks inserted in a glass rod. At the close of the experiment when the cylinder is being agitated the escaping baryta water forms a large quantity of the whitish precipitate as it washes down the side of the cylinder.

being set free than oxygen is being consumed. This feature of the experiment demonstrates what is known as intramolecular respiration, a kind of respiration which can go on independently of the entrance of the oxygen. See the author's larger "Elementary Botany" page 58.

Demonstration 28.

173. Respiration in a leafy plant.—We may take a potted plant which has a well-developed leaf surface and place it under a tightly fitting bell jar. Under the bell jar there also should be placed a small vessel containing baryta water. A similar apparatus should be set up, but with no plant, to serve as a check. The experiment must be set up in a room which is not frequented by persons, or the carbon dioxide in the room from respiration will vitiate the experiment. The bell jar containing the plant should be covered with a black cloth to prevent starch formation. In the course of ten or twelve hours, if everything has worked properly, the baryta water under the jar with the plant will shew the film of barium carbonate, while the other one will show none. Respiration, therefore, takes place in a leafy plant as well as in germinating seeds.

Fig. 80.
Test for liberation of carbon dioxide from leafy plant during respiration. Baryta water in smaller vessel. (Sachs.)

Synopsis.—Respiration (taking in oxygen and giving off carbon dioxide) occurs in all plants during growth.

Respiration takes place actively in germinating seeds and opening buds and flowers.

Respiration without access of oxygen (intramolecular respiration) takes place, in germinating seeds for example, in addition to normal respiration.

Respiration in plants is the same process as in animals.

The carbon dioxide from respiration may be detected by testing the air in the vessel where the plant is growing with a lighted taper (the taper is extinguished), or by baryta water (the baryta water absorbs carbon dioxide, forming the insoluble barium carbonate), or by lime water (the lime water absorbs carbon dioxide, forming the insoluble calcium carbonate = chalk).

Access of oxygen is necessary for the growth of most plants. (Some bacteria will only grow in the absence of oxygen.)

Respiration is a breaking-down process. (Changes take place in the protoplasm, the entering oxygen uniting with some of the carbon and oxygen of the protoplasm and forming CO_2.) Compare this with the burning of plant substance.

Respiration transforms energy in the plant, which is manifested by an elevation of the temperature of the plant substance, so that the plant gains some heat; it is also manifested by growth.

Comparison of respiration and starch formation.

Starch formation or Photosynthesis.	Carbon dioxide is taken in by the plant and oxygen is liberated. Starch is formed as a result of the metabolism, or chemical change. The process takes place only in green plants, and in the green parts of plants, that is, in the presence of the chlorophyll. (Exception in purple bacterium.) The process only takes place under the influence of sunlight. It is a building-up process, because new plant substance is formed.
Respiration.	Oxygen is taken in by the plant and carbon dioxide is liberated. Carbon dioxide is formed as a result of the metabolism, or chemical change. The process takes place in all plants whether they possess chlorophyll or not (exceptions in anaerobic bacteria). The process takes place in the dark as well as in the sunlight. It is a breaking-down process, because combustion of plant substance occurs.

Material and apparatus.—Peas soaked for 24 hours in cold water (enough for class and for demonstration).

Peas germinated, and with roots about 20*mm* long. A few should be started 4 or 5 days in advance of the time they are wanted.

Wide-mouthed bottles, or cylinders, with glass plates and vaseline, to close them, or corks (glass plates are better).

Tapers, or soft wood splinters for flaming.

Baryta water (saturated solution of barium hydrate in water) in tightly stoppered bottle.

Watch glasses for baryta water.

For demonstration 27: glass cylinder about 35*cm* high by 5*cm* in diameter; perforated rubbor cork to fit very tightly; S manometer made from glass tubing about 6*mm* diameter; mercury; small glass jar and vial; support as indicated in demonstration 27; some sticks of caustic potash; baryta water; a stout needle.

For demonstration 28: potted plant; bell jar to cover; baryta water.

CHAPTER XVII.

GROWTH.

174. Meaning of growth.—By growth is usually meant an increase in the bulk of the plant accompanied generally by an increase in plant substance. Among the lower plants growth is easily studied in some of the fungi.

175. Growth of roots.—For the study of the growth of roots we may take any one of many different plants. The seedlings of such plants as peas, beans, corn, squash, pumpkin, etc., serve excellently for this purpose.

Exercise 36.

176. To study growth of roots.—The seeds, a handful or so, are soaked in water for about 12 hours, and then placed between layers of paper or between the folds of cloth, which must be kept quite moist but not very wet, and should be kept in a warm place. (See demonstration 2.)

The primary or first root (radicle) of the embryo pushes its way out between the seed coats at the small end. When the seeds are well germinated, select several which have the root 4–5*cm* long. With a crow-quill pen we may now mark the terminal portion of the root off into very short sections as in fig. 81. The first mark should be not more than 1*mm* from the tip, and the others not more than 1*mm* apart. Now place the seedlings down on damp filter paper, and cover with a bell jar so that they will remain moist, and if the season is cold place them in a warm room. At intervals of 8 or 10 hours, if convenient, observe them and note the further growth of the root. Sketch the root with the marks at the beginning of the experiment, and at the different times the observations are taken. Where does the elongation take place? Determine this by the marks on the root which separate. Where is the region of greatest elongation? Does the region of greatest elongation change?

177. The region of elongation.—While the root has elongated, the region of elongation *is not at the tip of the root. It lies a little distance back from the tip,* beginning at about *2mm* from the tip and extending over an area represented by from 4 to 5 of the millimeter marks. The root shown in fig. 66 was marked at 10 A.M. on July 5. At 6 P.M. of the same day, 8 hours later, growth had taken place as shown in the middle figure. At 9 A.M. on the following day, 15 hours later, the growth is represented in the lower one. Similar experiments upon a number of seedlings gives the same result: the region of elongation in the growth of the root is situated a little distance back from the tip. Further back very little or no elongation takes place, but growth in diameter continues for some time, as we should discover if we examined the roots of growing pumpkins, or other plants, at different periods.

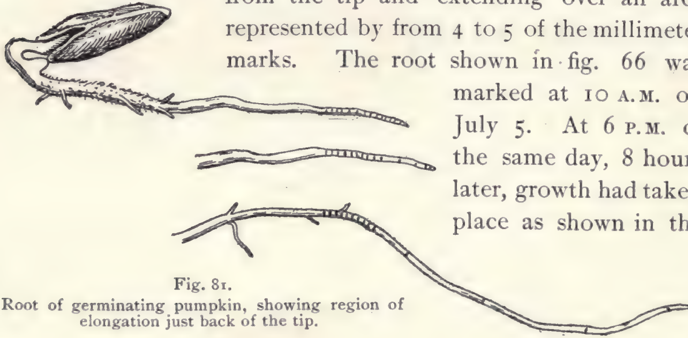

Fig. 81.
Root of germinating pumpkin, showing region of elongation just back of the tip.

178. Movement of region of greatest elongation.—In the region of elongation the areas marked off do not all elongate equally at the same time. The middle spaces elongate most rapidly and the spaees marked off by the 6, 7, and 8 *mm* marks elongate slowly, those farthest from the tip more slowly than the others, since elongation has nearly ceased here. The spaces marked off between the 2–4*mm* marks also elongate slowly, but soon begin to elongate more rapidly, since that region is becoming the region of greatest elongation. Thus the region of greatest elongation moves forward as the root grows, and remains approximately at the same distance behind the tip.

Exercise 37.

179. Growth of the stem.—We may use a bean seedling growing in the soil. At the junction of the leaves with the stem there are enlargements. These are the *nodes*, and the spaces on the stem between successive nodes are the *internodes*. We should mark off several of these internodes, especially the younger ones, into sections about 5*mm* long. Now observe these at several times for two or three days, or more. The region of elongation is greater than in the case of the roots, and extends back further from the end of the stem. In some young garden bean plants the region of elongation extended over an area of 40*mm* in one internode.

180. Force exerted by growth.—One of the marvellous things connected with the growth of plants is the force which is exerted by various members of the plant under certain conditions. Observations on seedlings as they are pushing their way through the soil to the air often show us that considerable force is required to lift the hard soil and turn it to one side. A very striking illustration may be had in the case of mushrooms which sometimes make their way through the hard and packed soil of walks or roads. That succulent and tender plants should be capable of lifting such comparatively heavy weights seems incredible until we have witnessed it. Very striking illustrations of the force of roots are seen in the case of trees which grow in rocky situations, where rocks of considerable weight are lifted, or small rifts in large rocks are widened by the lateral pressure exerted by the growth of a root, which entered when it was small and wedged its way in.

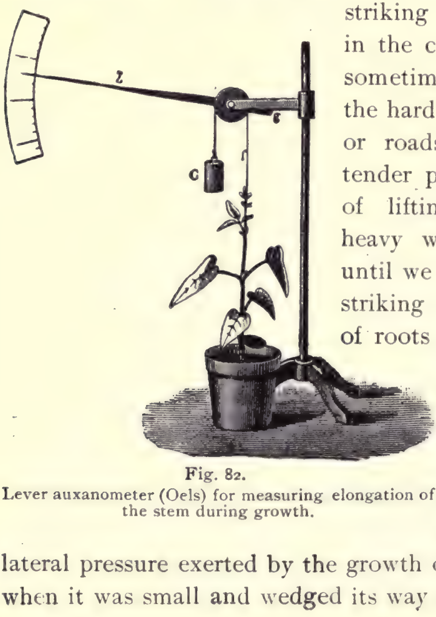

Fig. 82.
Lever auxanometer (Oels) for measuring elongation of the stem during growth.

If the season of the year is one that will permit, make some observations on the force exerted by seedlings in coming through the hard earth; of mushrooms coming up through dry and hard earth; of the wedging of roots in the crevices of rocks. Or recall and note any observations of this kind made in the past. One has only to note the immense size and weight of some trees to understand the force which must have been expended during their growth in lifting up the food materials for these massive objects.

181. Energy of growth.—This is manifested in the comparative size of the members of a given plant. To take the sunflower for example, the lower and first leaves are comparatively small. As the plant grows larger the leaves are larger, and this increase in size of the leaves increases up to a maximum period, when the size decreases until we reach the small leaves at the top of the stem. The zone of maximum growth of the leaves corresponds with the maximum size of the leaves on the stem. The rapidity and energy of growth of the stem is also correlated with that of the leaves, and the zone of maximum growth is coincident with that of the leaves. It would be instructive to note it in the case of other plants.

Exercise 38.

182. To study zone of maximum growth.—Study the zone of maximum growth in several plants which may be at hand. Some plants may be obtained for use from conservatories. Other plants may be collected during the growing season and preserved for this purpose. Corn plants, for example, can be gathered at maturity in the early autumn or late summer. They may be carefully pressed entire, and mounted on large sheets, or on pasteboard. The zones of maximum growth of the stem as well as of the leaves can be studied from these preserved plants. The plants in this condition will serve this purpose for several years.

For other experiments and studies on growth see the author's larger "Elementary Botany."

Synopsis.

Growth.

- An increase in the bulk or size of the plant. (Parts of the plant become longer and stouter.)
- Growth in length of the root takes place most actively a few millimeters back from the tip.
- The region of elongation of the root changes as the root becomes longer.
- Growth in length is the result of the elongation of the newly formed cells [the formative region (*i.e.*, where new cells are formed) is in the root tip].
- The stem grows in a similar way, but the region of elongation extends over a greater area than in the root.
- As a result of the increase in the size of plants by growth, great force is exerted, sufficient to move considerable amounts of hard earth ; or, in the case of trees, to even split rocks, or to lift up during growth the entire plant material in trunk and branches.
- The energy of growth during the season, or during the life of an annual, varies. It is low at first, as manifested by the small size of the members, then it increases to a maximum, then decreases.

Material and apparatus.—Seedlings of squash, or pumpkin, or peas, etc., grown in a germinator free from earth. The seeds should be started a week to ten days before they are wanted, so that the roots will be about 3*cm* to 4*cm* long. (See demonstration 2 for preparing seedlings.) Several moist chambers; large corks upon which some of the seedlings can be pinned.

India ink and crow-quill pen for marking the roots.

Seedlings grown in soil in pots with the stems just appearing above the soil.

Potted begonias; entire corn plants (may be pressed and preserved dry); or small but mature sunflower plants (also may be preserved dry).

CHAPTER XVIII.

MOVEMENT IN PLANTS DUE TO IRRITABILITY.

183. Movement in response to stimulus.—Beside the growth movements which take place in plant parts, the parts of plants show certain movements which are due to irritability. In this kind of movement the plant is influenced by some exciting cause, called a *stimulus.* The stimulus acts upon the irritable part of the plant, and in response to this movement occurs. We can easily study the effect of several different kinds of stimuli.

184. Influence of the earth on the direction of growth.—In the germination of the seeds which we have used in some of the earlier experiments it has probably been observed that the direction which the root and stem take upon germination is not due to the position in which the seed happens to lie. Under normal conditions we have seen that the root grows downward and the stem upward.

Exercise 39.

185. To study the influence of the earth on roots.—Take seedlings grown in a germinator which are free from the soil. Pin several seedlings to a cork in such a way that the stems and roots of different ones will be lying in different directions. Mark off the tip of the root of several with ink, as in paragraph 176. Cut off the extreme tip from a few of the roots. Place the cork in a moist chamber, with an abundance of water or saturated paper in the bottom. On the following day observe the positions of the roots and stems. Sketch and annotate. In the case of the roots marked into millimeter spaces determine the *motor zone* (region of curvature) of the root. Comparing these with the roots from which the tip was cut determine the *perceptive zone* (the zone which receives the stimulus). Now turn the cork in another position, leave for a day and note the result.

Exercise 40.

186. Influence of the earth on stems and leaves.—Place rapidly growing potted plants horizontally. Seedlings in pots, or young plants, or potted hyacinths are good ones to use. In the course of a day observe the positions of the stems and leaves. Sketch some of them.

187. Gravity acts as a stimulus.—Knight found that the stimulus which influences the root to turn downward is the force of gravity. The reaction of the root in response to this stimulus is *geotropism*, a turning influenced by the earth. This term is applied to the growth movements of plants influenced by the earth with regard to direction. While the motor zone lies back of the root tip, the latter receives the stimulus, and is the perceptive zone. If the root tip is cut off the root is no longer geotropic, and will not turn downward when placed in a horizontal position. Growth toward the earth is *progeotropism*. The lateral growth of secondary roots is *diageotropism*.

188. The result with stems.—The stem, on the other hand, which was placed in a horizontal position has become again erect.

Fig. 83.
Germinating pea placed in a horizontal position.

Fig. 84.
In twenty-four hours gravity has caused the root to turn downward.

Figures 83, 84.—Progeotropism of the pea root.

This turning of the stem in the upward direction takes place in the dark as well as in the light, as we can see if we start the experiment at nightfall, or place the plant in the dark. This upward growth of the stem is also influenced by the earth, and therefore is a case of geotropism. The special designation in the case of upright stems is *negative geotropism*, or *apogeotropism*, or the stems are said to be *apogeotropic*. Place a rapidly growing potted plant in a horizontal position by laying the pot on its side. The ends

of the shoots will soon turn upward again. Young bean plants growing in a pot began within two hours to turn the ends of the shoots upward.

Horizontal leaves and shoots can be shown to be subject to the same influence, and are therefore *diageotropic*.

189. Influence of light. — Not only is light a very important factor for plants during starch formation, it exerts great influence on plant growth and movement.

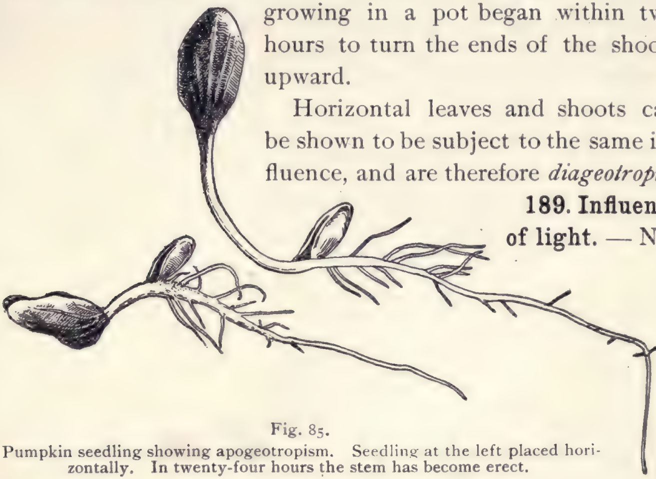

Fig. 85.
Pumpkin seedling showing apogeotropism. Seedling at the left placed horizontally. In twenty-four hours the stem has become erect.

Demonstration 29.

190. To prepare plants grown in the dark —Three or four weeks before these plants are wanted for study the teacher may plant a sufficient number of seeds (radish or other seeds) in small pots for the class to study. Several different kinds of seeds may be used for comparison if desired. Place one lot of the pots in a warm but very dark place. They may be put in a box, and the box can be then covered with two or three layers of black cloth, sufficient to shut out all light. Keep the box in a warm room, and occasionally open it to water the plants if necessary. The lot kept in the light should have the same temperature conditions. If preferred the pupils can plant the seeds, and place those to be grown in the dark in a common box. This is preferable if it is convenient for the pupils to do it.

Exercise 41.

191. Influence of light on the growth of plants.—When the plants have grown for about two weeks they will be ready for study. Compare the plants grown in the dark with those grown in the light. Which lot have the longer stems? What influence then does light have on growth in

length? Which plants have the larger leaves? What influence does light have on the development of leaves? What is the difference in color of the plants? What is the cause of this? Which lot of plants have the firmer tissues? What is the cause of the difference in the firmness of the tissues? Sketch a plant grown in the dark; sketch one to the same scale grown in the light.

Exercise 42.

192. Influence of light on the direction of growth.—Take potted seedlings and place them near a window so that they will have a one-sided illumination. Or place them in a box which has a small opening at one side. After a day or two observe the position of the seedlings. Does light have an influence on the direction of growth? What is the direction with reference to the source of light? Sketch one of the plants, and indicate on the sheet the direction of the rays of light.

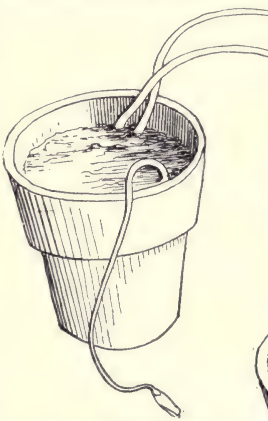

Fig. 86.
Radish seedlings, grown in the dark, long, slender, not green.

193. Influence of light on the position of leaves.—Take potted plants with a number of leaves, and place them near a window for several days or a week. Observe the position of the leaves at the beginning of the experiment, and after a week's time. What is the position of the leaves with reference to the source of light? Can you tell why the leaves take this position?

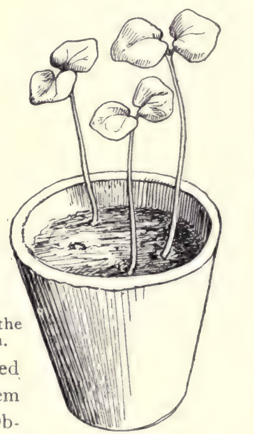

Fig. 87.
Radish seedlings grown in the light, shorter, stouter, and green in color. Growth retarded by light.

194. Retarding influence of light on growth.—We have only to return to the experiments performed in growing plants in the dark to see one of the influences which light exerts on plants. The plants grown in the dark were longer and more

slender than those grown in the light. Light then has a retarding influence on the elongation of the stem.

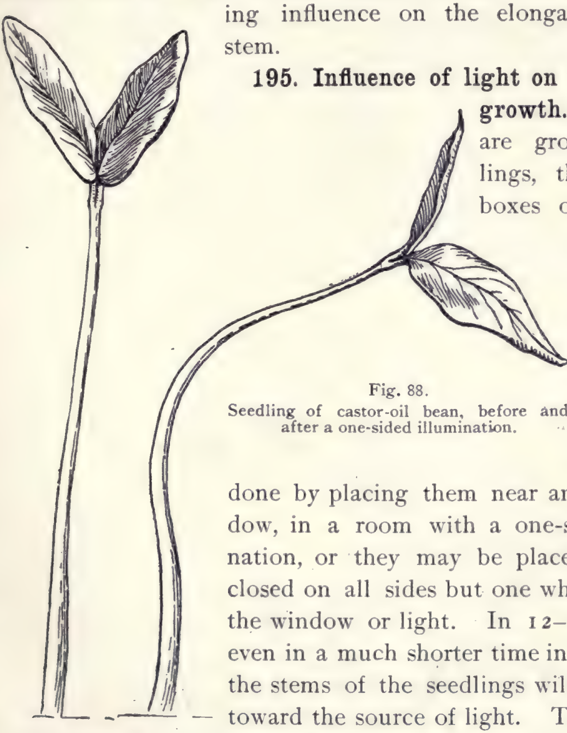

Fig. 88.
Seedling of castor-oil bean, before and after a one-sided illumination.

195. Influence of light on direction of growth.—While we are growing seedlings, the pots or boxes of some of them should be placed so that the plants will have a one-sided illumination. This can be done by placing them near an open window, in a room with a one-sided illumination, or they may be placed in a box closed on all sides but one which is facing the window or light. In 12–24 hours, or even in a much shorter time in some cases, the stems of the seedlings will be directed toward the source of light. This influence exerted by the rays of light is *heliotropism*, a turning influenced by the sun or sunlight.

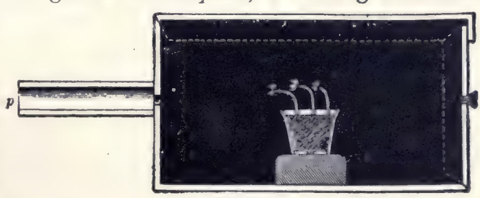

Fig. 89.
Dark chamber with opening at one side to show heliotropism. (After Schleichert.)

196. Diaheliotropism.—Horizontal leaves and shoots are *diaheliotropic* as well as *diageotropic*. The general direction which leaves assume under this influence is that of placing them with the upper surface perpendicular to

the rays of light which fall upon them. Leaves, then, exposed to the brightly lighted sky are, in general, horizontal. This position is taken in direct response to the stimulus of light.

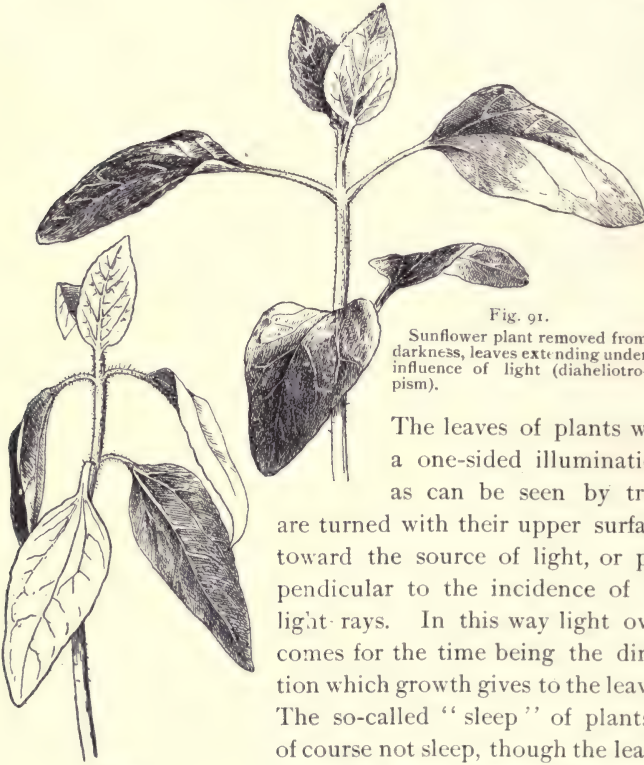

Fig. 91.
Sunflower plant removed from darkness, leaves extending under influence of light (diaheliotropism).

Fig. 90.
Sunflower plant. Epinastic condition of leaves induced during the day in darkness.

The leaves of plants with a one-sided illumination, as can be seen by trial, are turned with their upper surfaces toward the source of light, or perpendicular to the incidence of the light rays. In this way light overcomes for the time being the direction which growth gives to the leaves. The so-called "sleep" of plants is of course not sleep, though the leaves "nod," or hang downward, in many cases. There are many plants in which we can note this drooping of the leaves at nightfall, and in order to prove that it is not determined by the time of day we can resort to a well-known experiment to induce this condition during the day. The plant which has been used to illustrate this is the sunflower. Some of these plants, which were grown in a box, when they were

about 35*cm* high were covered for nearly two days, so that the light was excluded. At midday on the second day the box was removed, and the leaves on the covered plants are well represented by fig. 90, which was made from one of them. The leaves of the other plants in the box which were not covered were horizontal, as shown by fig. 91. Now on leaving these plants, which had exhibited induced "sleep" movements, exposed to the light they gradually assumed the horizontal position again.

Synopsis.

Irritability.
- Plants are irritable, that is, they respond to certain stimuli.
- The force of gravity stimulates the tip of the root, and causes the root to turn downward.
  - The "motor zone," in response to this stimulus, is coincident with the region of elongation of the root.
  - The perceptive zone is in the root tip.
- The force of gravity stimulates the stem to turn upwards (or away from the earth).
  - Geotropism.
    - Progeotropism (in first root).
    - Diageotropism (in lateral roots).
    - Apogeotropism (in stems).
- Influence of light.
  - Stems(horizontal stems are diaheliotropic) grow towards the light (heliotropic).
  - Leaves turn so as to face the light (unless the light is very strong, when they may turn their edge toward the light).
  - Light retards growth of stems, since stems grown in the dark are longer.
  - Plants do not "sleep"; when the leaves turn downward at night it is because the influence of light is removed and the leaf is free to turn in the direction caused by growth, the growth being more active usually on the upper side of the leaf after it pushes out from the bud.

Material and apparatus.—Seedlings, moist chambers, corks and pins, as in Chapter XVII.

Seedlings in pots (beans, squash or pumpkin), 10*cm* to 15*cm* high. Potted hyacinths if they can be obtained.

Seedlings grown in pots in the dark (about three weeks old), others of the same age grown in the light.

Some dark boxes with small opening at one side, to receive some of the pots of seedlings.

If possible some sunflower plants grown in pots, plants about 20*cm* to 30*cm* high, and tall dark boxes to cover them when desired.

Sunflower plants should be started two or three months in advance. Potted oxalis, which is often grown in conservatories, is better to show induced "sleep" movements.

PART II: MORPHOLOGY AND LIFE HISTORY OF REPRESENTATIVE PLANTS.

CHAPTER XIX.

SPIROGYRA.

197. Convenience in studying spirogyra.—In our study of protoplasm and some of the processes of plant life we became acquainted with the general appearance of the plant spirogyra. It is now a familiar object to us. And in taking up the study of representative plants of the different groups, we shall find that in knowing some of these lower plants the difficulties of understanding methods of reproduction and relationship are not so great as they would be if we were entirely ignorant of any members of the lower groups.

198. Form of spirogyra.—We have found that the plant spirogyra consists of simple threads, with cylindrical cells attached end to end. We have also noted that each cell of the thread is exactly alike, with the exception of certain "holdfasts" on some of the species. If we should examine threads in different stages of growth we should find that each cell is capable of growth and division, just as it is capable of performing all the functions of nutrition and assimilation. The cells of spirogyra then multiply by division. Not simply the cells at the ends of the threads but any and all of the cells divide as they grow, and in this way the threads increase in length.

199. Conjugation of spirogyra.—Under certain conditions, when vegetative growth and multiplication cease, a process of reproduction takes place which is of a kind termed sexual

reproduction. If we select mats of spirogyra which have lost their deep green color, we are likely to find different stages of this sexual process, which in the case of spirogyra and related plants is called *conjugation.*

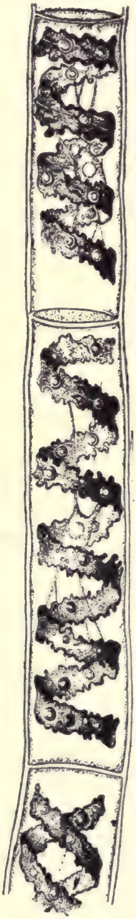

Fig. 92.
Thread of spirogyra, showing long cells, chlorophyll band, nucleus, strands of protoplasm, and the granular wall layer of protoplasm.

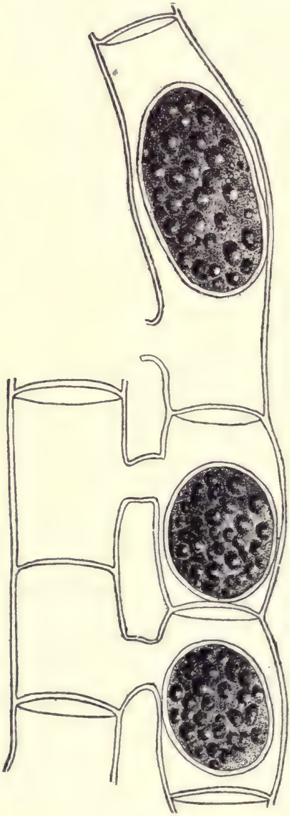

Fig. 93.
Zygospores of spirogyra.

Demonstration 30.

200. To demonstrate the conjugation of spirogyra.—From a tangle of the threads on a glass slip, which are conjugating, mount a few in water, tease the threads apart, place on a cover glass, and prepare for observation under the microscope. Let the pupils sketch conjugating cells, and make notes upon the different stages of the passage of the protoplasm, and on the other characters of the fruiting threads, as outlined below.

201. Conjugation.—If the material is in the right condition we will see in certain of the cells an oval or elliptical body. If we note carefully the cells in which these oval bodies are situated, there will be seen a tube at one side which connects with an empty cell of a thread which lies near as shown in fig. 93. If

we search through the material we may see other threads connected in this ladder fashion, in which the contents of the cells are in various stages of collapse from what we have seen in the growing cell. In some the protoplasm and chlorophyll band have moved but little from the wall; in others they form a mass near the centre of the cell, and again in others we will see that the content of the cell of one of the threads has moved partly through the tube into the cell of the thread with which it is connected.

This suggests to us that the oval bodies found in the cells of one thread of the ladder, while the cells of the other thread were empty, are formed by the union of the contents of the two cells. In fact that is what does take place. This kind of union of the contents of two similar or nearly similar cells is *conjugation*. The oval bodies which are the result of this conjugation are *zygotes*, or *zygospores*. When we are examining living material of spirogyra in this stage it is possible to watch this process of conjugation. Fig. 94 represents the different stages of conjugation of spirogyra.

202. How the threads conjugate, or join.—The cells of two threads lying parallel put out short processes. The tubes from two opposite cells meet and join. The walls separating the contents of the two tubes dissolve so that there is an open communication between the two cells. Each one of these cells corresponds to a sexual organ. This process of conjugation is a sexual process. The process here is a very simple one because any cell of the thread without any particular change in size or form may become a sexual organ. The cell which loses its protoplasm is the supplying cell, while the one in which the zygospore is formed is the receiving cell. Before the movement of the protoplasm begins we cannot tell which is to be the supplying cell or the receiving cell.

The passage of the protoplasm from one cell to another can only be seen under the most favorable conditions, and then with living material. It is possible, however, in preserved material

to find cells which have the protoplasm in some of these different stages. When the zygospores are being studied one should look for some cells in these stages.

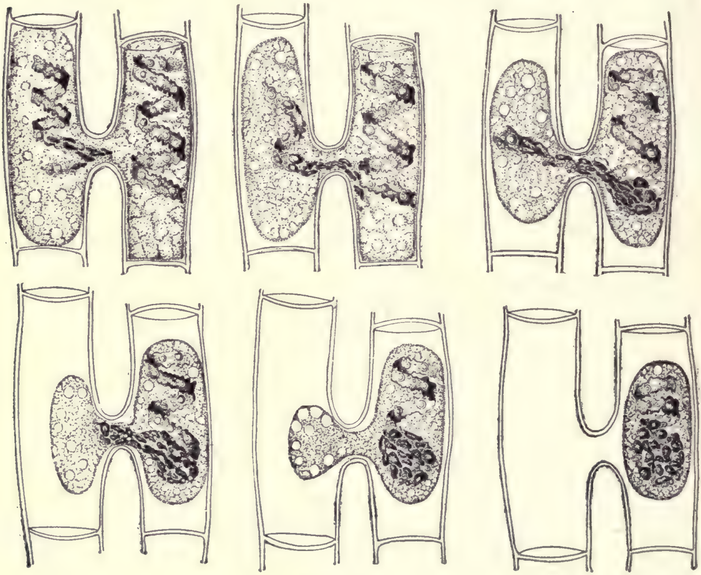

Fig. 94.
Conjugation in spirogyra; from left to right beginning in the upper row is shown the gradual passage of the protoplasm from the supplying cell to the receiving cell.

203. The zygospore.—This zygospore now acquires a thick wall which eventually becomes brown in color. The chlorophyll color fades out, and a large part of the protoplasm passes into an oily substance which makes it more resistant to conditions which would be fatal to the vegetative threads. The zygospores are capable therefore of enduring extremes of cold and dryness which would destroy the threads. They pass through a "resting" period, in which the water in the pond may be frozen, or dried, and with the oncoming of favorable conditions for growth in the spring or in the autumn they germinate and produce the green thread again.

For further reading on spirogyra and its relatives see the author's larger "Elementary Botany," Chapter XV.

Synopsis.

Spirogyra.
- Vegetative stage; single unbranched threads, composed of cylindrical cells end to end.
  - Cells all alike.
  - Grows by division and elongation of all the cells.
- Sexual stage; conjugation of like cells.
  - Receiving and supplying cells, not differentiated.
  - Result of conjugation, a *zygospore*.
- The zygospore after a period of rest produces the spirogyra thread again.

Material.—Spirogyra in conjugation, showing different stages, as well as the zygospores. The material may be collected fresh, or it may be preserved in 2% formalin collected in advance or purchased from supply companies.

Microscope, etc.

CHAPTER XX.

THE GREEN FELT: VAUCHERIA.

204. Description of vaucheria.—The plant vaucheria usually occurs in dense mats floating on the water or lying on the damp soil. The texture and feeling of one of these mats reminds one of "felt," and the species are sometimes called the "green felts." The threads are quite coarse and are branched. Upon examination with the microscope we find that the threads are continuous, that is, there are no cross-walls as in spirogyra dividing the thread up into short cells. The chlorophyll is in small oval bodies scattered over the inside of the wall of the tube. These are the characters of the vegetative threads. A portion of a vegetative thread is shown in fig. 95. Cross-walls are formed only where reproductive cells or organs are formed, which cut them off from the re-

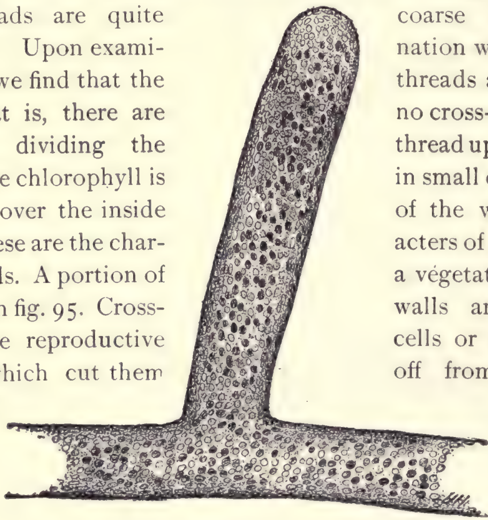

Fig. 95.
Portion of branched thread of vaucheria.

mainder of the vegetative thread. This plant multiplies in several ways which would be too tedious to detail here. The sexual reproduction,* however, should be studied if possible,

* Oedogonium may be studied in place of vaucheria if preferred and if material is more easily obtained. Vaucheria is usually more abundant and

since the organs of reproduction can be readily seen, usually much easier to study than in any of the plants belonging to the higher groups. If fresh material is not at hand, that which has been preserved in alcohol or formalin will serve very well. Often excellent material is to be found in greenhouses growing on the soil of pots during the winter, especially if one obtains from outside in the autumn some bulbs of arisæma (jack-in-the-pulpit) with soil near them for potting. Fresh material of vaucheria in fruit is found easily during the autumn or spring. At this time a quantity should be preserved. The sexual organs are usually more abundant when the threads appear somewhat yellowish or yellow green.

Exercise 43.

205. Gross characters of vaucheria.—If fresh material is at hand which was growing in water, note how firmly the threads are tangled together; compare with spirogyra in this respect. Can you make out in this condition that the threads are branched? This branched condition of vaucheria is one of the reasons for the dense tangle of threads. Note the coarse feeling; compare with spirogyra in this respect.

If material on the soil is at hand, note that it is not necessary that all species grow in water. Note here also the dense tangle of threads. Lift up a tuft with the needle; compare the effect on the threads with that of spirogyra when a tuft of the latter is lifted in the same way. Compare the "feeling" of the threads with that of spirogyra.

Demonstration 31.

206. Sexual reproduction in vaucheria.—Mount a few threads of fruiting vaucheria in water for microscopic study. If prepared slides are at hand they will answer for the demonstration. Let each pupil make a sketch of the sexual organs, and make notes of the form of the same; also note the continuity of the threads, cross-walls only being formed in connection with the reproductive organs. Let them compare the different stages found in the formation of the ripe egg.

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both kinds of the sexual organs are more easily found and understood, those of oedogonium being more complicated. See Chapters XVI and XVII of the author's larger "Elementary Botany."

207. Vaucheria sessilis; the sessile vaucheria.—In this plant the sexual organs are sessile, that is they are not borne on a stalk as in some other species. The sexual organs usually occur several in a group. Fig. 96 represents a portion of a fruiting plant.

Fig. 96.
Young antheridium and oogonium of Vaucheria sessilis, before separation from contents of thread by a septum.

208. Sexual organs of vaucheria. Antheridium.—The antheridia are short, slender, curved branches from a main thread. A septum is formed which separates an end portion from the stalk. This end cell is the *antheridium.* Frequently it is collapsed or empty as shown in fig. 97. The protoplasm in the antheridium forms numerous small oval bodies each with two slender lashes, the cilia. When these are formed the antheridium opens at the end and they

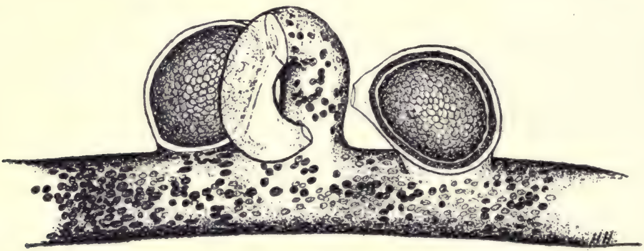


Fig. 97.
Vaucheria sessilis, one antheridium between two oogonia.

escape. It is after the escape of these spermatozoids that the antheridium is collapsed. Each spermatozoid is a male gamete.

209. Oogonium.—The oogonia are short branches also, but they become large and somewhat oval. The septum which separates the protoplasm from that of the main thread is as we see near the junction of the branch with the main thread. The

oogonium, as shown in the figure, is usually turned somewhat to one side. When mature the pointed end opens and a bit of the protoplasm escapes. The remaining protoplasm forms the large rounded egg cell which fills the wall of the oogonium. In some of the oogonia which we examine this egg is surrounded by a thick brown wall, with starchy and oily contents. This is the fertilized egg (sometimes called here the oospore). It is freed from the oogonium by the disintegration of the latter, sinks into the mud and remains here until the following autumn or spring, when it grows directly into a new plant. The spermatozoids are very difficult to see and one should not expect to study them here. Fertilization is brought about by the spermatozoids swimming in at the open end of the oogonium, when one of them makes its way down into the egg and fuses with the nucleus of the latter.

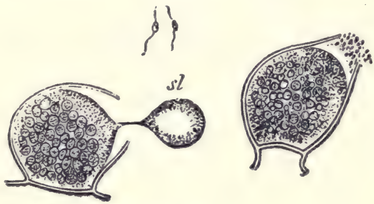


Fig 98.
Vaucheria sessilis; oogonium opening and emitting a bit of protoplasm; spermatozoids; spermatozoids entering oogonium. (After Pringsheim and Goebel.)

210. Vaucheria compared with spirogyra.—In vaucheria we have a plant which is very interesting to compare with spirogyra in several respects. In spirogyra growth takes place in all cells, that is in all parts of the thread, while in vaucheria growth is confined to the ends of the threads and the ends of the branches. This is a distinct advance on spirogyra. Again in spirogyra any part of the thread (any cell) may become one of the sexual organs. In vaucheria the sexual organs are special branches, which are short, and further, the two organs are different in size so that they can readily be distinguished long before the time for fertilization. Then in vaucheria the supplying cell does not give all its content to the receiving cell, but only a bit of the protoplasm in the form of a minute body, the spermatozoid.

Synopsis.

Vaucheria.
- Vegetative stage; branched threads, continuous, growth confined to the ends of the threads and ends of the branches.
- Sexual stage; fertilization of an egg by a minute sperm nucleus.
- Sexual organs differentiated.
  - Antheridium (male organ). Contains numbers of small spermatozoids.
  - Oogonium (female organ). Contains one egg.
- Result of fertilization is the formation of a fertilized egg (oospore), which after a period of rest grows into the vaucheria plant again.

Material.—Freshly collected material of one of the species of vaucheria which is in fruit. It can be obtained from the water of ponds or ditches, or it is very often found growing on soil of pots in greenhouses. If preferred it may be collected in advance and be preserved in 2% formalin, or it may be purchased of supply companies.

Microscope, etc.

CHAPTER XXI.

FUNGI: THE BLACK MOULD.

Demonstration 32.

211. To grow the mould.—This plant may be grown by placing old bread, or partly decaying fruits, as bananas, or the peelings of lemons or oranges in a moist chamber. Set this in a warm place for about one week. Then the plant may be grown on potatoes as described in paragraph 49, or one may take the material for study directly from the bread. It should be studied before it becomes very old.

Exercise 44.

212. Mycelium.—Before the black heads of the fungus appear, note the delicate fluffy white tufts of threads which appear on the surface of the bread or other substance on which the fungus is growing. These threads are the mycelium, and a single thread is a mycelium thread, or "*hypha*."

Search on the margins of old cultures where the threads come in contact with paper (some sheets of paper should be placed by the sides of the cultures) or the sides of the vessels for "runners," long threads of mycelium which touch the place of support here and there. Are there tufts of upright threads at the points of contact which bear black heads? Try to find the connection of the black threads with the creeping mycelium.

If the mycelium has not been studied in a previous chapter the teacher can mount some here for demonstration. Let the pupils note the branched, colorless threads, and that there are no cross-walls. Note the granular protoplasm.

At the microscope let each pupil note the long dark-colored stalks which bear the rounded "heads"; the latter are the sporangia. If the spores are mature the sporangium wall is perhaps broken and the spores more or less scattered. If so, note the remnant of the wall as a small collar below the enlarged end of the stalk. The enlarged end of the stalk is the "columella." In the younger stages of the sporangium, note the columella arched up within the sporangium. Trace the stalks down to their attach-

ment with the mycelium. Is there only one at this point of attachment, or are there several? Are there any rhizoids present at the point of attachment? Sketch the different stages.

213. Description of the mucor fruit.—We shall probably note at once that the stalks or upright threads which support the heads are stouter than the threads of the mycelium.

These upright threads soon have formed near the end a cross-

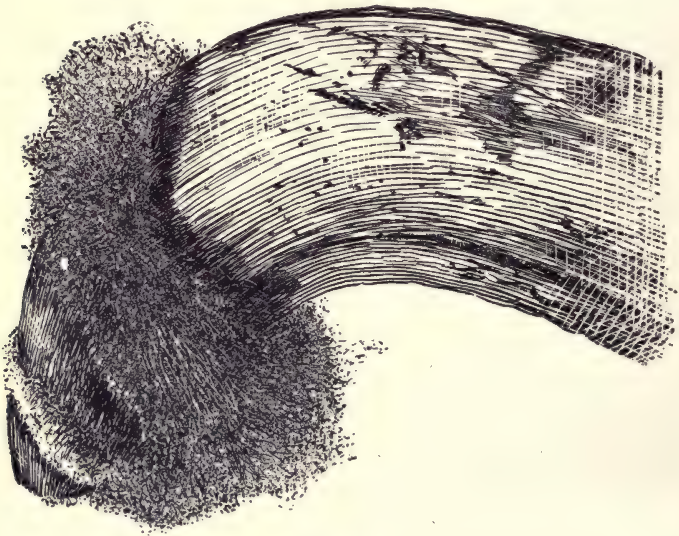


Fig. 99.
Portion of banana with a mould (Rhizopus nigricans) growing on one end.

wall which separates the protoplasm in the end from the remainder. This end cell now enlarges into a vesicle of considerable size, the head as it appears, but to which is applied the name of *sporangium* (sometimes called gonidangium, because it encloses the *gonidia*).

At the same time that this end cell is enlarging the cross-wall is arching up into the interior. This forms the *columella*. All the protoplasm in the sporangium now divides into gonidia.

Fig. 100.
Group of sporangia of a mucor (Rhizopus nigricans) showing rhizoids and the stolon extending from an older group.

These are small rounded or oval bodies. The wall of the sporangium becomes dissolved, except a small collar around the stalk which remains attached below the columella (fig. 101). By this means the gonidia are freed. These gonidia germinate and produce the mycelium again.

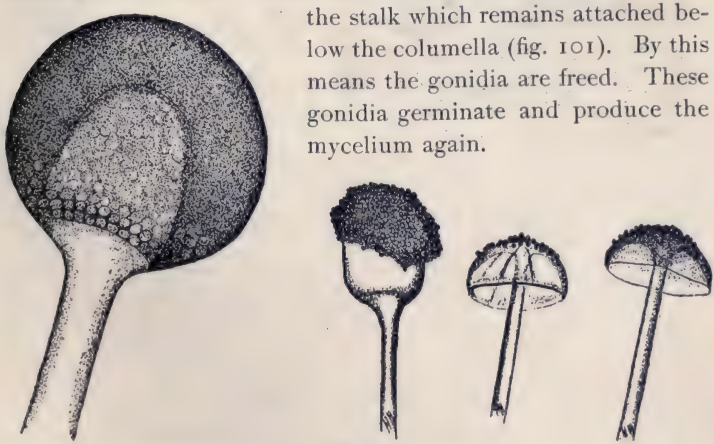


Fig. 101.
A mucor (Rhizopus nigricans); at left nearly mature sporangium with columella showing within; in the middle is ruptured sporangium with some of the gonidia clinging to the columella; at right two ruptured sporangia with everted columella.

214. To show the "runners" of the black mould.—If some filter paper is placed by the side of the bread or other substance in the moist chamber, some of the threads of the fungus may be induced to grow over on to it. If the mould is the species illustrated in fig. 100 there may be seen "runners" like those in the figure with clusters of the sporangia at certain points. Certain threads of the mycelium grow along on the paper like a strawberry "runner" does over the ground. Here and there the myceliium touches the paper and forms little rootlets, and also a group of the sporangia. It is because of this character that the plant is called Mucor stolonifer, the stolon bearing mould. Or the other name of "rhizopus" is given because it is "root-footed."

Synopsis.

The black mould.
- Grows on old bread, decaying fruits, vegetables, etc.
- Vegetative part; delicate whitish threads, which branch, and form a cottony-like mat, called the *mycelium.*
- Fruiting part; upright stout threads bear black heads, called sporangia.
- Fruiting part.
  - Several fruiting threads in a cluster, with rhizoids at base.
  - Sporangium.
  - Sporangium wall.
  - Columella.
  - Spores (or gonidia).
- Sexual stage not treated of here.

Material.—Cultures of the black mould on bread or baked potatoes. See paragraph 49 for making the cultures.

Microscope, etc.

If conjugation of a mould is desired, it may be purchased of supply companies.

CHAPTER XXII.

FUNGI (CONTINUED): WHEAT RUST.

(*Puccinia graminis.*)

215. Importance of the rusts.—The fungi known as "rusts" are very important ones to study, since all the species are parasitic, and many produce serious injuries to crops.

Exercise 45.

216. Black rust of wheat.—Dried stalks of wheat or oats with the black spots of this stage of the rust are excellent for the study. Sketch a portion of an affected stalk, showing the spots in natural size and form. With a hand lens examine the spots more carefully. Observe that the black mass of color has burst through the epidermis of the wheat. Describe the appearance.

217. Red rust of wheat.—This stage is found abundantly on the leaves of the wheat and oats, etc. Dried leaves which have been pressed are good for the study. Observe the color of the spots, and compare with that of the black-rust spots. Compare the size also. Examine with a hand lens, and determine whether the mass of spores making up the rust color, break through the epidermis. Sketch a portion of the leaf showing the characters observed.

218. Cluster-cup stage on the barberry.—Leaves of the barberry may be pressed dry and preserved for study. Sketch a leaf showing the location and character of the spots. Describe the form and character of the spots. Examine the spots on both sides of the leaves with a hand lens. Describe what you see. If leaves of the barberry with the cluster cups cannot be obtained some other cluster-cup fungus may be used, but it should be understood that the others are not connected with the wheat rust (except some growing on shrubs closely related to the barberry).

Demonstration 33.

219. To demonstrate the different stages of the wheat rust under the microscope.—*Black rust:* with a knife scrape out the material from a few black spots, tease out in water on a glass slip, and mount as usual. *Red rust:* pre-

pare in the same way from the yellow spots. To demonstrate the *cluster cups*, good cross-sections of the leaf through a spot should be made, or prepared slides should be obtained. Let the pupils sketch the form of the different spores, and other characters, and make notes of the observations.

To demonstrate mycelium in the tissues, use the carnation rust which can be obtained in winter in greenhouses where the carnations are grown (see Chapter XV, paragraph 159), or fresh wheat leaves may be preserved in alcohol for making sections.

220. Wheat rust (Puccinia graminis).—The wheat rust is one of the best known of these fungi, since a great deal of study has been given to it. One form of the plant occurs in long

Fig. 102. Wheat leaf with red rust, natural size.

Fig. 103. Portion of leaf enlarged to show sori.

Fig. 104. Black rust. Natural size.

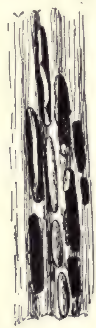


Fig. 105. Enlarged.

Fig. 106 Single sorus.

Figures 102, 103.—Puccinia graminis, red-rust stage (uredo stage).
Figures 104–106.—Black rust of wheat, showing sori of teleutospores.

reddish-brown or reddish pustules, and is known as the "red rust" (figs. 102, 103). Another form occurs in elongated black pustules, and this form is the one known as the "black rust" (figs. 104–107). These two forms occur on the stems, blades, etc., of the wheat, also on oats, rye, and some of the grasses.

221. Teleutospores of the black-rust form.—Scrape off some portion of one of the black pustules (sori), tease it out in water on a slide, and examine with a microscope, to see numer-

ous spores, composed of two cells, and having thick, brownish walls as shown in fig. 108. Usually there is a slender brownish stalk on one end. These spores are called *teleutospores*. They are somewhat oblong or elliptical, a little constricted where the septum separates the two cells, and the end cell varies from ovate

Fig. 107.
Head of wheat showing black rust spots on the chaff and awns.

Fig. 108.
Teleutospores of wheat rust, showing two cells and the pedicel.

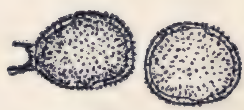


Fig. 109.
Uredospores of wheat rust, one showing remnants of the pedicel.

to rounded. The mycelium of the fungus courses between the cells, just as is found in the case of the carnation rust, which belongs to the same family (see Chapter XV).

222. Uredospores of the red-rust form.—If we make a similar preparation from the pustules of the red-rust form we shall see that instead of two-celled spores they are one-celled.

The walls are thinner and not so dark in color, and they are covered with minute spines. They have also short stalks, but these fall away very easily. These one-celled spores of the red-rust form are called "uredospores." The uredospores and teleutospores are sometimes found in the same pustule.

It was once supposed that these two kinds of spores belonged to different plants, but now it is known that the one-celled form, the uredospores, is a form developed earlier in the season than the teleutospores.

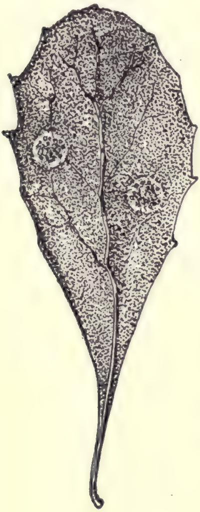


Fig. 110.
Barberry leaf with two diseased spots, natural size.

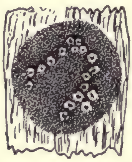


Fig. 111.
Single spot showing cluster cups enlarged.

Fig. 112.
Two cluster cups more enlarged, showing split margin.

Figures 153-155.—Cluster-cup stage of wheat rust.

223. Cluster-cup form on the barberry.—On the barberry is found still another form of the wheat rust, the "*cluster cup*" stage. The pustules on the under side of the barberry leaf are cup-shaped, the cups being partly sunk in the tissue of the leaf, while the rim is more or less curved backward against the leaf, and split at several places. These cups occur in clusters on the affected spots of the barberry leaf as shown in fig. 111. Within the cups numbers of one-celled spores (orange in color, called æcidiospores) are borne in chains from short branches of the mycelium, which fill the base of the cup. In fact the wall of the cup (peridium) is formed of similar rows of cells, which, instead of separating into spores, remain united to form a wall. These cups are usually borne on the under side of the leaf.

For a fuller study of the wheat rust and of other fungi see the author's larger "Elementary Botany," Chapters XX, XXI.

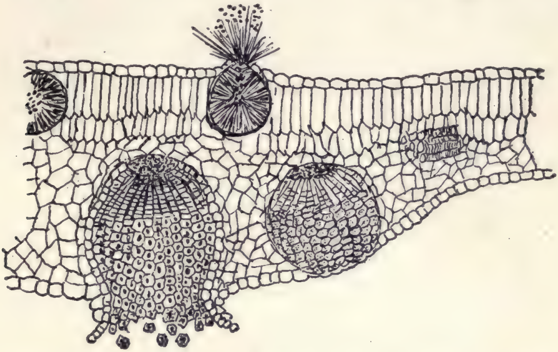


Fig. 113.
Section through leaf of barberry at point affected with the cluster-cup stage of the wheat rust; spermagonia above, æcidia below. (After Marshall-Ward.)

Synopsis.

- Wheat rust.
  - A parasite on grains, grasses, and on the barberry.
  - Vegetative part of plant; mycelium growing within the tissues of the host.
  - **Fruiting** part of the plant.
    - Four forms.
      - 1st. Red rust (one-celled spores in pustules on blades and stems of the wheat).
      - 2d. Black rust (two-celled spores in pustules on the blades and stems of the wheat).
      - 3d. Cluster cup (one-celled spores in chains within a structure called a peridium, or cup on leaves and stems of barberry).
      - 4th. Spermagonia (small flask-shaped bodies accompanying the cluster cups, of unknown function).

Material.—Dried stalks of wheat or oats with the black-rust spots; dried leaves with the red-rust spots; leaves of the barberry with the cluster cups. (If the barberry leaves cannot be obtained, another species of cluster cup may be used to illustrate the æcidial stage, but it should be remembered that other cluster cups are not connected with the life history of the wheat rust.)

For satisfactory studies of the cluster-cup stage, sections through the cup should be made from fresh material, or sections already made may be purchased from the supply companies.

Microscope, etc.

CHAPTER XXIII.

FUNGI (Concluded): THE WILLOW MILDEW.

(*Uncinula salicis.*)

224. Description of the mildew.—The willow mildew belongs to a very interesting group of the fungi known as the powdery mildews. These mildews are very common on the leaves, and even stems, flowers, and fruits, of various plants. It is a very easy matter to find them during the summer or late autumn and to press a number of the leaves to preserve for future study.

The mycelium grows on the outside of the parts of the host, so that it gives a whitish, "mildewed" appearance to the affected places. Very short branches (haustoria) from the mycelium enter the epidermal cells of the host and draw nutriment from the leaves or other parts, and supply the fungus with the materials for growth. This nutriment is taken at the expense of the host, and often considerable injury to it is thus done, which results in a sickly appearance of the host, or even in a deformity, the leaves or stems being curled or dwarfed. Immense numbers of small, colorless spores (gonidia) are borne in chains on some of the threads, and these piled up on the surface of the leaf give it a powdered appearance.

After this powdery stage of the fungus has formed, another kind of fruit of the fungus is developed. This may be detected by numerous minute black specks seated on the white mycelium, as shown in fig. 114. Each one of these black specks is a fruit body.

Exercise 46.

225. The Willow Mildew.—Take dried leaves, or those freshly collected, which show some of the whitish mycelium, and numerous black fruit bodies.

Fig. 114.
Leaves of willow showing willow mildew. The black dots are the fruit bodies (perithecia) seated on the white mycelium.

Observe the white mycelium. Is it scattered unevenly over the surface of the leaf, or does it form more or less circular spots? Is there any difference in

the color or appearance of the leaf in the spots where the mycelium is seated? * Try to remove some of the mycelium with a needle, to see that it consists of threads which are on the surface of the leaf.

Fruit bodies. Observe the minute black specks seated on the mycelium. Are all of them black, or dark in color? If there are any yellowish ones how do they compare with the dark ones as to size? How do they compare as to age? With a hand lens examine them more carefully. Can you see any dark-colored threads extending out from the fruit body? Can you see their form?

Demonstration 34.

226. The fruit bodies.—Place a drop of water on a glass slip. Touch the point of a scalpel or knife to the water and then scrape the surface of the leaf gently where there are a number of the black bodies. The capillarity of the water will hold some of the fruit bodies to the point of the knife. From this tease off the fruit bodies with a needle into the drop of water on the slip. Separate them well and put on the cover glass.

Let each pupil examine the fruit bodies under the microscope. Note the form of surface markings and the appendages. Sketch.

227. The asci and spores which they contain.—Take this same preparation, crush the fruit bodies by gently pressing on the cover glass above them, until the fruit bodies are cracked open, and some of the sacs containing the spores are pressed out (see fig. 116). Let the pupils examine and sketch them.

The gonidia may be demonstrated by using leaves where the fruit bodies are not abundant, but which possess an abundance of the mycelium (see fig. 115).

228. Fruit bodies of the willow mildew.—On the mycelium there appear numerous black specks scattered over the affected places of the leaf. These are the fruit bodies (*perithecia*). When examined with a low power of the microscope, each one is seen to be a rounded body, from which radiate numerous

* If the leaves are not old the portions where the mycelium is seated may be more or less yellow, showing an injury; but if the leaves are quite old and nearly ready to fall, the green color may have disappeared more rapidly from the unaffected parts of the leaf, for the fungus gives some stimulus to the leaf, and often this is manifested by the green color remaining longer in the affected parts of the old leaves.

filaments, the *appendages*. Each one of these appendages is coiled at the end into the form of a little hook. Because of these hooked appendages this genus is called *uncinula*. This rounded body is the *perithecium*.

229. Asci and ascospores.—While we are looking at a few of these through the microscope with the low power, we should press on the cover glass with a needle until we see a few of the

Fig. 115.

Willow mildew; bit of mycelium with erect conidiophores, bearing chain of gonidia; gonidium at left germinating.

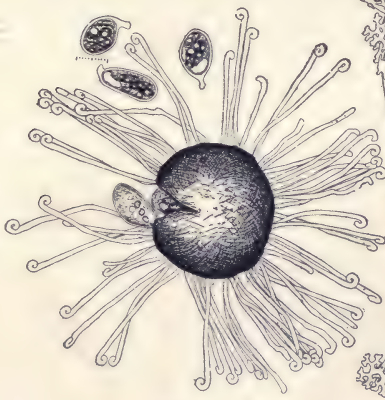


Fig. 116.

Fruit of willow mildew, showing hooked appendages. Genus uncinula.

Fig. 117.

Fruit body of another mildew with dichotomous appendages. Genus microsphæra.

Figures 116, 117.—Perithecia (perithecium) of two powdery mildews, showing escape of asci containing the spores from the crushed fruit bodies.

perithecia rupture. If this is done carefully we see several small ovate sacs issue, each containing a number of spores, as shown in fig. 116. Such a sac is an *ascus*, and the spores are *ascospores*.

Synopsis.—

Willow mildew.
- Vegetative part of the plant: mycelium on the surface of the host sends suckers (haustoria) into the cells of the host.
- Propagative stage of the plant: short erect threads which bear chains of spores (gonidia).
- Fruiting part of the plant (perfect stage).
  - Perithecium with hooked appendages.
    - Perithecium contains sacs (asci).
      - The sacs contain the spores (ascospores).

Material.—Dried and pressed leaves of willow with the white mildew, also older stages showing the numerous black "specks," the fruit bodies, of the mildew. Other species of the mildew may be used if preferred.

Microscope, etc.

CHAPTER XXIV.

LIVERWORTS (HEPATICÆ).

(*Marchantia polymorpha.*)

230. Form of marchantia.—The marchantia (M. polymorpha) has been chosen for study because it is such a common and easily obtained plant, and also for the reason that with comparative ease all stages of development can be obtained. It illustrates also very well certain features of the structure of the liverworts.

The plants are of two kinds, male and female. The two different organs, then, are developed on different plants. In appearance, however, before the beginning of the structures which bear the sexual organs they are practically the same.

The plant forms a flattened, green, leaf-like body which lies on the damp soil or clings closely to wet rock. It is shaped somewhat like an irregular ribbon, the margins more or less wavy, and the plant is branched in a forked manner as shown in fig. 118. Upon the under side are numerous hair-like bodies, the "rhizoids," which serve the purpose of root hairs in absorbing food solutions, and they also attach the plant to the substratum. The growing point of the thallus is in the little depression at the free end.

For fuller studies of the liverworts and for the sexual organs see the author's larger "Elementary Botany," Chapters XXII and XXIII.

Exercise 47.

231. Male plants.—Examine both surfaces of the "thallus" as the leaf-like body of the liverwort is called. Note where the rhizoids are attached. Sketch the plant, showing the rhizoids, the form of the thallus, and the um-

brella-shaped bodies on the upper surface. Note that the expanded part of this umbrella-shaped structure is crenate on the margin, giving it a lobed appearance, and that these lobes radiate from the centre. Search for little pits opening on the upper surface of these structures ; these are the opening of the chambers where the antheridia are borne. With a hand lens examine the upper surface of the thallus. Can you see that it is marked off into diamond-shaped areas, with a minute opening in the centre of each ? These openings are the stomates of the thallus. Observe that the central line of the thallus is thicker than the margins. This is the midrib.

Exercise 48.

232. Female plants.—Study these in a similar way, and compare. The thallus is very similar, the greater point of difference being in the umbrella-shaped structures. Note that the expanded portion is more deeply lobed, forming prominent rays. On the under surface observe the delicate hanging fringes. Underneath these the archegonia are borne. If material with ripe fruit is at hand preserved in formalin, observe the rounded capsules on short stalks which protrude from beneath these curtains. Sketch and describe all parts of the plant.

Exercise 49.

233. Sterile plants bearing cups and gemmæ.—Study these in a similar way. Note that the umbrella-shaped structures are absent. Observe the minute cups on the upper surface. With a hand lens note the minute flattened green bodies within the cups. These are the gemmæ, or buds, and serve as one means of propagating the plant.

Demonstration 35.

(*May be omitted.*)

234. Sexual organs.—The teacher may make demonstrations to show the sexual organs, and the spores and elaters. For the antheridia section the antheridial receptacle, and for the archegonia section the archegonial receptacle. Unless one is familiar with methods of sectioning these structures, it would be better to purchase prepared sections of these organs for the demonstration. See fig. 123.

Demonstration 36.

235. Spores and elaters.—When the fruit is ripe (see fig. 125) and the spores and elaters are escaping some may be mounted. They may be mounted in glycerine jelly. Such mounts will keep for a long time if cared

for, and will serve for successive years' study. Mounts may also be made from material preserved in formalin. Tease out a few of the spores and elaters from the capsule with needles, in a drop of alcohol on the glass slip. Melt a bit of glycerine jelly on a cover glass and just as the alcohol is evaporating from the slide lower the glycerine with the cover over them. See figure 126.

Spores and elaters from some other liverwort may be used if more convenient.

236. Antheridial plants.—One of the male plants is figured at 118. It bears curious structures, each held aloft by a short stalk. These are the antheridial receptacles. Each one is circular, thick, and shaped somewhat like a bi-convex lens. The upper surface is marked by radiating furrows, and the margin is crenate. Then we note, on careful examination of the upper surface, that there are numerous minute openings. If we make a thin section of this structure perpendicular to its surface we shall be able to unravel the mystery of its interior. Here we see, as shown in fig. 119, that each one of these little openings on the surface is an entrance to quite a large cavity. Within each cavity there is an oval or elliptical body, supported from the base of the cavity on a short stalk. This is an antheridium, and one of them is shown still more enlarged in fig. 120. This shows the structure of the antheridium, and that there are within several angular areas, which are divided by numerous straight cross-lines into countless tiny cuboidal cells, the *sperm mother cells*. Each of these

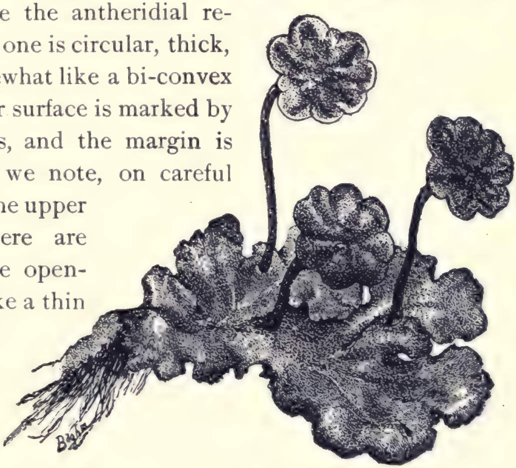


Fig. 118.
Male plant of marchantia bearing antheridiophores.

changes into a swiftly moving body resembling a serpent with two long lashes attached to its tail.

Fig. 119.
Section of antheridial receptacle from male plant of Marchantia polymorpha, showing cavities where the antheridia are borne.

237. Archegonial plants.—In fig. 122 we see one of the female plants of marchantia. Upon this there are also very curious structures, which remind one of miniature umbrellas.

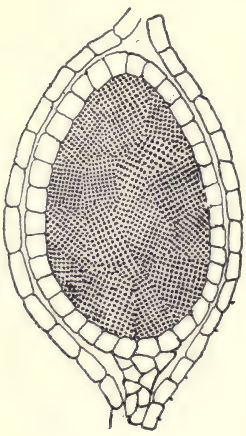


Fig. 120.
Section of antheridium of marchantia, showing the groups of sperm mother cells.

Fig. 121.
Spermatozoids of marchantia, uncoiling and one extended, showing the two cilia.

The general plan of the archegonial receptacle is similar to that of the antheridial receptacle, but the rays are more pronounced,

and the details of structure are quite different, as we shall see. Underneath the arms there hang down delicate fringed curtains. If we make sections of this in the same direction as we did of the antheridial receptacle, we shall be able to find what is

Fig. 122.
Marchantia polymorpha, female plants bearing archegoniophores.

secreted behind these curtains. Here we find the archegonia, but instead of being sunk in cavities their bases are attached to the under surface, while the delicate, pendulous fringes afford them protection from drying.

238. Sporogonium of liverworts. — If the sporogonium (spore-case) of marchantia cannot be obtained those of any other liverwort may be used.

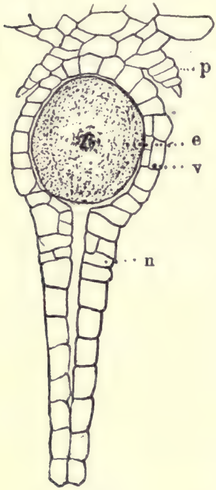


Fig. 123.
Marchantia polymorpha, archegonium with egg; *p*, curtain which hangs down around the archegonia; *e*, egg; *v*, venter of archegonium; *n*, neck of archegonium.

239. Sporogonium of marchantia.—If we examine the plant shown in fig. 124 we shall see oval bodies which stand out between the rays of the female receptacle, supported on short stalks. These are the sporogonia, or spore-cases. We can see that some of the spore-cases have opened, the wall splitting down from the apex in several lines. This is caused by the drying of the wall. These toothlike divisions of the wall now curl backward, and we can see the yellowish mass of the spores in slow motion, falling here and there. It appears also as if there were twisting threads which aided the spores in becoming freed from the capsule.

240. Spores and elaters.—If we take a bit of this mass of spores and mount it in water for examination with the microscope, we shall see that, besides the spores, there are very peculiar thread-like bodies, the markings of which remind one of a twisted rope. These are very long cells from the inner part of the spore-case, and their walls are marked by spiral thickenings. This causes them in drying, and also when they absorb moisture, to twist and curl in all sorts of ways. They thus aid in pushing the spores out of the capsule as it is drying.

241. How marchantia multiplies.—New plants of marchantia are formed by the germination of the spores, and growth of the same to the thallus. The plants may also be multiplied by parts of the old ones breaking away by the action of strong currents of water, and when they lodge in suitable

places grow into well-formed plants. As the thallus lives from year to year and continues to grow and branch the older portions die off, and thus separate plants may be formed from a former single one.

242. Buds, or gemmæ, of marchantia.—But there is another way in which marchantia multiplies itself. If we exam-

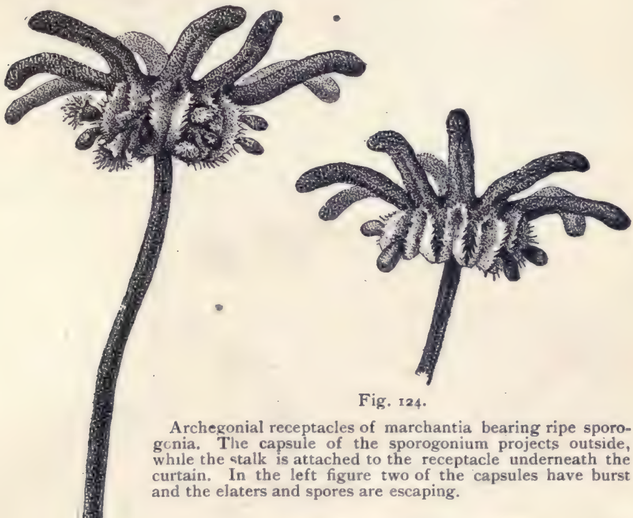


Fig. 124.

Archegonial receptacles of marchantia bearing ripe sporogonia. The capsule of the sporogonium projects outside, while the stalk is attached to the receptacle underneath the curtain. In the left figure two of the capsules have burst and the elaters and spores are escaping.

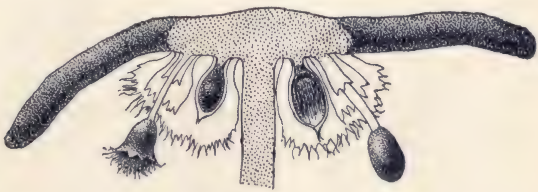


Fig 125.

Section of archegonial receptacle of Marchantia polymorpha; ripe sporogonia One is open, scattering spores and elaters; two are still enclosed in the wall of the archegonium. The junction of the stalk of the sporogonium with the receptacle is the point of attachment of the sporophyte of marchantia with the gametophyte.

ine the upper surface of such a plant as that shown in fig. 127, we shall see that there are minute cup-shaped or saucer-shaped

vessels, and within them minute green bodies. When these green buds free themselves from the cups they come to lie on one side and develop into new plants. It does not matter on

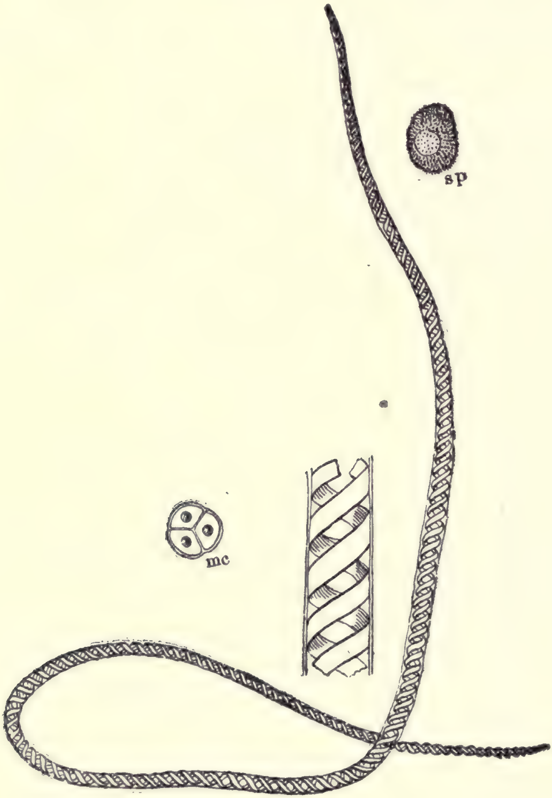


Fig. 126.
Elater and spore of marchantia. *sp*, spore ; *mc*, mother cell of spores, showing partly formed spores.

what side they lie, for whichever side it is, that will develop into the lower side of the thallus, and will form rhizoids, while the upper surface will develop the stomates.

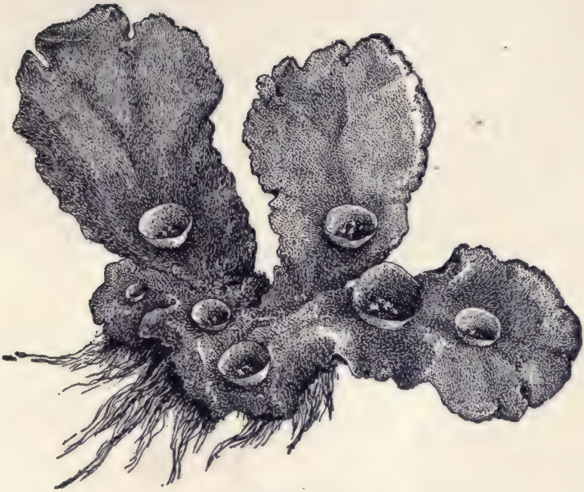


Fig. 127.
Marchantia plant with cupules and gemmæ; rhizoids below.

Synopsis.

- Marchantia (A liverwort).
  - Plant body; flattened, ribbon-like, green, with rhizoids on under surface; grows in moist situations.
  - Vegetative part. Three forms.
    - 1st. Plant with buds in little cups. The buds escape and propagate the plant.
    - 2d. Male plants.
      - Antheridial receptacle.
      - Antheridial cavities.
        - Antheridium.
        - Spermatozoids.
    - 3d. Female plants.
      - Archegonial receptacle.
        - Archegonium.
          - Egg.
  - Fruiting part.
    - Fruit capsule.
      - Capsule wall.
      - Spores.
      - Elaters.
    - Short stalk attaching fruit body to archegonial receptacle.

Material and apparatus.—Freshly collected plants, or if these cannot be had, plants preserved in 2% formalin, or in alcohol, may be used. Some plants dry are often useful if they are not to be had in any other condition.

Plants with the cups and gemmæ; male plants; and female plants.

For the study of the fruit bodies plants must be had either fresh (but this is quite impossible since they ripen in June and July) or better, plants with ripe fruit bodies may be preserved in 2% formalin.

For the demonstration of the sexual organs, and of the spores and elaters, the teacher may make sections, or purchase sections of supply companies. Hand lenses, or simple dissecting microscopes.

Microscope, etc., for demonstrations 35 and 36.

CHAPTER XXV.

MOSSES (MUSCI).

(*Polytrichum, or mnium.*)

243. The moss plant.—We are now ready to take up the more careful study of the moss plant. There are a great many kinds of mosses, and they differ greatly from each other in the finer details of structure. Yet there are certain general resemblances which make it convenient to take for study almost any one of the common species in a neighborhood, which forms abundant fruit. Some, however, are more suited to a first study than others.

Those mosses in which there is a marked difference between the male and female plants, like polytrichum, bryum, mnium, etc., are most suitable for the purpose. The male plants of these genera have the leaves at the end of the stem in a broad rosette. Both male and female plants should be collected, and the fruiting plants also. The latter bear above the leafy portion a stalked capsule. Polytrichum (known as pigeon wheat moss) is suggested here for the practical study, while mnium is here used to illustrate the mosses. It will be found useful occasionally to study a plant that is different from the one fully illustrated in the book, since it gives the student an opportunity for more independent work.

The Pigeon Wheat Moss (Polytrichum).

Exercise 50.

244. The fruiting plant.—Take entire plants, those with leafy stems bearing the stalked capsule. Sketch the entire plant. Note the stem (axis) and the three rows of leaves. Search for the rhizoids at the lower end of the stem. What is their color? Observe the capsule, its form.

Among the material search for those capsules representing several different ages. Very young ones are often collected when there appears to be nothing but a slender stalk, the capsule not yet being fully developed. Search on the capsule for the hairy hood, known as a *calyptra*. Remove this; note its form. Now at the end of the capsule note the conic lid (the operculum). Remove this, or examine older capsules where the lid has fallen away. Note the numerous teeth. When the lid is removed, are there any small granules (the spores) escaping? Compare the shape of the capsules of different ages.

Exercise 51.

245. The male plants.—Note the broad rosette of leaves at the end of the stem. Compare the arrangement of the leaves here with those lower down on the stem. Sketch. The antheridia (sing. antheridium) are borne in the centre of the rosette.

246. The female plants.—Compare with the male plants: what is the difference in the arrangement of the leaves? Can you suggest why the leaves are arranged differently in the two plants?

Demonstration 37.

(*May be omitted when necessary.*)

247. Demonstration of spores, etc.—The teacher can prepare mounts of the spores, and of a portion of the mouth (peristome) of the capsule for study. If it is desired also leaves may be examined under the microscope. The leaves are made up of a single layer of cells, except at the middle line where the cells are several layers thick, and long and narrow. The cells in the middle line form the "midrib" of the leaf. The teacher can also make sections through the ends of the male and female plants to demonstrate the sexual organs, or prepared slides representing these may be purchased for demonstration.

Description of the Moss, Mnium.

248. Mnium.—We will select here the plant shown in fig. 128. This is known as a mnium (M. affine), and one or another of the species of mnium can be obtained without much difficulty. The mosses, as we have already learned, possess an axis (stem) and leaf-like expansions, so that they are leafy-stemmed plants. Certain of the branches of the mnium stand upright, or nearly so, and the leaves are all of the same size at any given point on the stem, as seen in the figure.

There are three rows of these leaves, and this is true of most of the mosses.

249. Habit of mnium.—The mnium plants usually form quite extensive and pretty mats of green in shady moist woods or ravines. Here and there among the erect stems are prostrate ones, with two rows of prominent leaves so arranged that they remind one of some of the leafy-stemmed liverworts. If we examine some of the leaves of the mnium we will see that the greater part of the leaf consists of a single layer of green cells, just as is the case in the leafy-stemmed liverworts. But along the middle line is a thicker layer, so that it forms a distinct midrib. This is characteristic of the leaves of mosses, and is one way in which they are separated from the leafy-stemmed liverworts, the latter never having a midrib.

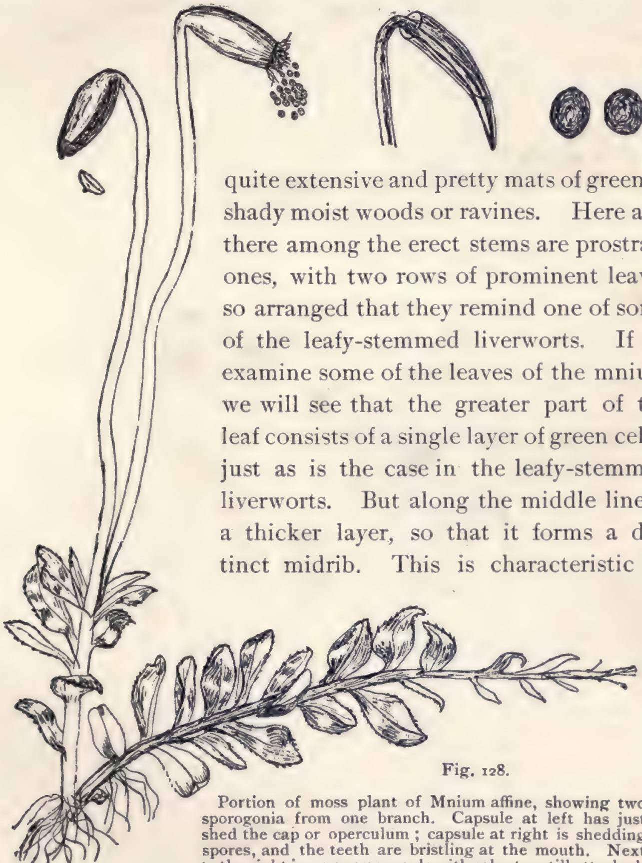


Fig. 128.

Portion of moss plant of Mnium affine, showing two sporogonia from one branch. Capsule at left has just shed the cap or operculum; capsule at right is shedding spores, and the teeth are bristling at the mouth. Next to the right is a young capsule with calyptra still attached; next are two spores enlarged.

250. The fruiting moss plant.—In fig. 128 is a moss plant "in fruit," as we say. Above the leafy stem a slender stalk bears the capsule, and in this capsule are borne the spores.

251. Sporogonium of the moss.—The sporogonium (spore-case) of a moss is illustrated in fig. 128. The sporogonium is the portion represented above the leafy part, and consists of a stalk and capsule. This was developed from the fertilized egg.

Fig. 129.
Female plant (gametophyte) of a moss (mnium), showing rhizoids below, and the tuft of leaves above which protect the archegonia.

Fig. 130.
Male plant (gametophyte) of a moss (mnium) showing rhizoids below and the antheridia at the centre above surrounded by the rosette of leaves.

The capsule is nearly cylindrical, bent downward, and supported on a long slender stalk.

Upon the capsule is a peculiar cap, shaped like a ladle or spatula, the *calyptra.*

252. Structure of the moss capsule.—At the free end on the moss capsule as shown in the case of mnium in fig. 128, after the remnant of the archegonium falls away, there is seen a conical lid which fits closely over the end. When the capsule is ripe this lid easily falls away, and can be brushed off, so that it is necessary to handle the plants with care if is desired to preserve this for study.

253. Opening of the capsule.—When the lid is brushed away as the capsule dries more, we see that the end of the capsule covered by the lid appears "frazzled." If we examine this end with the microscope we will see that the tissue of the capsule here is torn with great regularity, so that there are two rows of narrow, sharp teeth which project outward in a ring around the opening. If we blow our "breath" upon these teeth they will be seen to move, and as the moisture disappears and reappears in the teeth, they close and open the mouth of the capsule, so sensitive are they to the changes in the humidity of the air. In this way all of the spores are prevented to some extent from escaping from the capsule at one time.

254. The male and female moss plants.—The two plants of mnium, shown in figs. 129, 130, are quite different, as one can easily see, and yet they belong to the same species. One is a female plant, while the other is a male plant. The sexual organs, then, in mnium, as in many others of the mosses, are borne on separate plants. The archegonia are borne at the end of the stem, and are protected by somewhat narrower leaves which closely overlap and are wrapped together. They are similar to the archegonia of the liverworts.

The male plants of mnium are easily selected, since the leaves at the end of the stem form a broad rosette with the antheridia, and some sterile threads packed closely together in the centre. The ends of the mass of antheridia can be seen with the naked eye, as shown in fig. 130.

Synopsis.

- Moss plant (Polytrichum or other moss).
  - Plant body, a small leafy stem, with rhizoids.
  - Vegetative part of plant. Three forms.
    - Protonema (branched green threads which precede the leafy stem).
    - Male plants with a rosette of leaves at the end.
      - Antheridia.
        - Spermatozoids.
    - Female plants, leaves closed together at the end.
      - Archegonia.
        - Archegonium contains egg.
  - Fruiting part.
    - Fruit capusule.
      - Capsule wall.
      - Lid.
      - Teeth at mouth.
      - Spores.
    - Stalk.
  - (The hood is not a part of the capsule, but is the remains of the archegonium.)

Material and apparatus.—The pigeon wheat moss (polytrichum) is an excellent one to study, but one should not be confined to this if it is easier to collect other species which show strong differences between male and female plants. Male and female plants, as well as plants with fruit, some of which should possess the "hood," should be preserved dry, or in 2% formalin.

Free hand, or prepared, sections of the sexual organs.

Apparatus, the same as in Chapter XXIV.

CHAPTER XXVI.

FERNS (FILICINEÆ).

(*The polypody, or Christmas fern.*)

255. Importance of study of ferns.—In taking up the study of the ferns we find plants which are very beautiful objects of nature and thus have always attracted the interest of those who love the beauties of nature. But they are also very interesting to the student, because of certain remarkable peculiarities of the structure of the fruit bodies, and especially because of the intermediate position which they occupy within the plant kingdom, representing in the two phases of their development the primitive type of plant life on the one hand, and on the other the modern type. We will begin our study of the ferns by taking that form which is the more prominent, the fern plant itself.

256. Selection of fern for study.—There are several ferns which answer equally well for study. It is important to have the entire plant, underground stem, roots, and leaves, and what is of especial importance, some of the leaves should have the "fruit dots." The common polypody (Polypodium vulgare) is widely distributed, and will be useful for the practical study, even though the Christmas fern here is used to illustrate the descriptive part. There should, however, be no necessity for limiting the study to a certain species, since in one locality one species can be more easily obtained, while in another locality another species may be more convenient to study.

Exercise 52.

257. The fern plant.—Take entire plants, if the common polypody, note the creeping stem (root-stock or rhizome), the numerous brown scales cov-

ering it, the bud at the anterior end covered also with brown scales. Observe the numerous dark slender roots.

Note the leaves, some of them perhaps plain (sterile) on the under side, while others have numerous circular brown or blackish dots, the fruit dots where the sporangia (spore-cases) and spores are borne. Describe the form of the leaf. Name the different parts. Sketch the entire plant. Sketch a portion of the under side of the spore-bearing leaf, to show the fruit dots. Compare the polypody with several other species of ferns if possible.

Exercise 53.

258. The scattering of the spores.—If the study is made at a time when the ferns with spores just ripe cannot be collected out doors, get some leaves from greenhouses. Take those leaves where the fruit dots appear quite black, and under the lens the sporangia appear like shiny rounded black bodies. Place a leaf on white paper in a dry room, with the under side uppermost. In the course of an hour or earlier watch for showers of spores which are scattered around the leaf, Sometimes in a dry room these begin to scatter in the course of a few minutes. The success of this exercise will depend on the material being in the right condition. After a little experience in collecting it is not difficult to get the right material.

Demonstration 38.

259. To show the sporangia.—These can be shown from sporangia which are just ripe, or from older material which has been dried, or preserved in formalin or alcohol. Scrape off a few of the sporangia from the "fruit dot." Mount them in water for examination under the microscope.

LET EACH STUDENT EXAMINE the form and structure. Sketch a sporangium seen from the side. Name the different parts, the slender stalk, the enlarged spore-case. In the spore-case make out a prominent row of cells over the back and upper part (the *annulus*), note the "lip cells" in front, one each side of the place where the sporangium opens. If there are any spores in this preparation note and describe them ; sketch one also. If there are none to be seen in the preparation made for the study of the sporangium the teacher can mount some for study if desired.

To see the snapping of the sporangium fresh ripe material may be mounted in water ; then draw under the cover glass some glycerine and watch the result.

260. The Christmas fern.—One of the ferns which is very common in the Northern States, and occurs in rocky banks and woods, is the well-known Christmas fern (Aspidium acrosti-

choides) shown in fig. 131. The leaves are the most prominent part of the plant, as is the case with most if not all our native ferns. The stem is very short and for the most part under the surface of the ground, while the leaves arise very close together, and thus form a rosette as they rise and gracefully bend outward. The leaf is elongate and reminds one somewhat of a plume with the pinnæ extending in two rows on opposite sides of the midrib. These pinnæ alternate with one another, and at the base of each pinna is a little spur which projects upward from the upper edge. Such a leaf is said to be pinnate. While all the leaves have the same general outline, we notice that certain ones, especially those toward the centre of the rosette, are much narrower from the middle portion toward the end. This is because of the shorter pinnæ here.

Fig. 131.
Christmas fern (Aspidium acrostichoides).

261. Fruit "dots" (sorus, indusium).—If we examine the under side of such short pinnæ of the Christmas fern we see that

there are two rows of small circular dots, one row on either side of the pinna. These are called the "fruit dots," or sori (a single one is a sorus). If we examine it with a low power of the microscope, or with a pocket lens, we will see that there is a circular disk which covers more or less completely very minute objects, usually the ends of the latter projecting just beyond the edge if they are mature. This circular disk is what is called the *indusium*, and it is a special outgrowth of the epidermis of the leaf here for the protection of the spore-cases. These minute objects underneath are the fruit bodies, which in the case of the ferns and their allies are called *sporangia*. This indusium in the case of the Christmas fern, and also in some others, is attached to the leaf by means of a short slender stalk which is fastened to the middle of the under side of this shield.

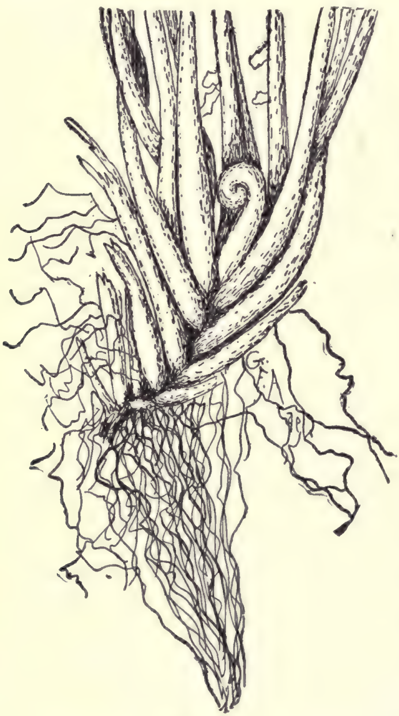


Fig. 132.
Rhizome with bases of leaves, and roots of the Christmas fern.

262. Sporangia.—If we section through the leaf at one of the fruit dots, or if we tease off some of the sporangia so that the stalks are still attached, and examine them with the microscope, we can see the form and structure of these peculiar bodies. Different views of a sporangium are shown in fig. 137. The slender portion is the stalk, and the larger part is the spore-case proper. We should examine the

structure of this spore-case quite carefully, since it will help us to understand better than we otherwise could the remarkable operations which it performs in scattering the spores.

263. Structure of a sporangium.—If we examine one of the sporangia in side view as shown in fig. 137, we note a prominent row of cells which extend around the margin of the dorsal edge from near the attachment of the stalk to the upper front angle. The cells are prominent because of the thick inner walls, and the thick radial walls which are perpendicular to the inner walls. The walls on the back of this row and on its sides are very thin and membranous. We should make this one

Fig. 133.
Rhizome of sensitive fern (Onoclea sensibilis).

carefully, for the structure of these cells is especially adapted to a special function which they perform. This row of cells is termed the *annulus*, which means a little ring. While this is not a complete ring, in some other ferns the ring is nearly complete.

264. The lip cells.—In the front of the sporangium is another peculiar group of cells. Two of the longer ones resemble the lips of some creature, and since the sporangium opens between them they are sometimes termed the lip cells. These lip cells

are connected with the upper end of the annulus on one side and with the upper end of the stalk on the other side by thin walled cells, which may be termed connective cells, since they hold each lip cell to its part of the opening sporangium. The cells on the side of the sporangium are also thin-walled. If we now examine a sporangium from the back, or dorsal edge as we say, it will appear as in the left-hand figure. Here we can see how very prominent the annulus is. It projects beyond the surface of the other cells of the sporangium. The spores are contained inside this case.

Fig. 134.
Under side of pinna of Aspidium spinulosum showing fruit dots (sori).

265. Opening of the sporangium and dispersion of the spores.—If we take some fresh fruiting leaves of the Christmas

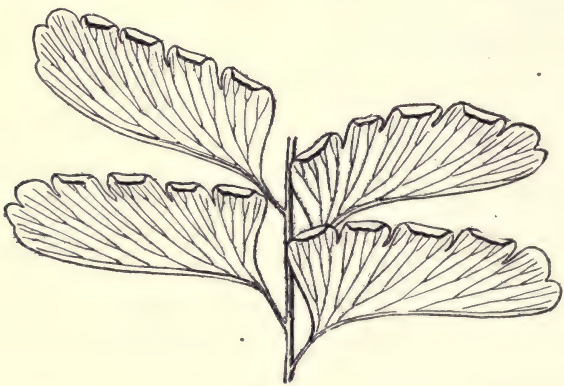


Fig. 135.
Four pinnæ of adiantum, showing recurved margins which cover the sporangia.

fern, or of any one of many of the species of the true ferns just at the ripening of the spores, and place a portion of a leaf on a piece of white paper in a dry room, in a very short time we shall see that the paper is being dusted with minute brown objects which fly out from the leaf. Now if we take a portion of the same

leaf and place it under the low power of the microscope, so that the full rounded sporangia can be seen, in a short time we note that the sporangium opens, the upper half curls backward as shown in fig. 138, and soon it snaps quickly, to near its former position, and the spores are at the same time thrown for a considerable distance. This movement can sometimes be seen with the aid of a good hand lens.

266. How does this opening and snapping of the sporangium take place?—We are now more curious than ever to see just how this opening and how the snapping of the sporangium takes place. We should now mount some of the fresh sporangia in water and cover with a cover glass for microscopic examination. A drop of glycerine should be placed at one side of the cover glass on the slip so that the edge of the glycerine will come in touch with the water. Now as one looks through the microscope to watch the sporangia, the water should be drawn from under the cover glass with the aid of some bibulous paper, like filter paper, placed at the edge of the cover glass on the opposite side from the glycerine. As the glycerine takes the place of the water around the sporangia it draws the water out of the cells of the annulus, just as it took the water out of the cells of the spirogyra as we learned some time ago. As the water is

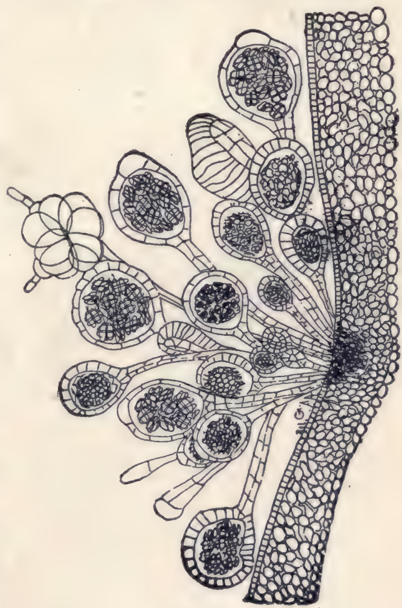


Fig. 136.

Section through sorus of Polypodium vulgare showing different stages of sporangium, and one multicellular capitate hair.

drawn out of these cells there is produced a pressure from without, the atmospheric pressure upon the glycerine. This causes the walls of these cells of the annulus to bend inward, because, as we have already learned, the glycerine does not pass through the walls nearly so fast as the water comes out.

267. Working of the annulus.—Now the structure of the cells of this annulus, as we have seen, is such that the inner walls and the perpendicular walls are stout, and consequently they do not

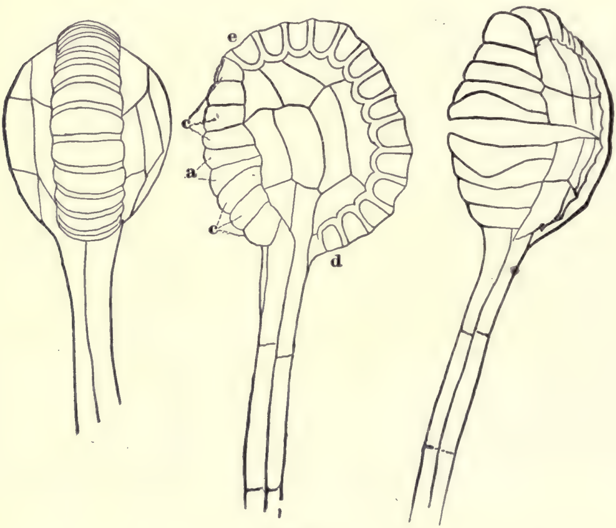


Fig. 137.
Rear, side, and front views of fern sporangium. *d*, *e*, annulus ; *a*, lip cells.

bend or collapse when this pressure is brought to bear on the outside of the cells. The thin membranous walls on the back (dorsal walls) and on the sides of the annulus, however, yield readily to the pressure and bend inward. This, as we can readily see, pulls on the ends of each of the perpendicular walls, drawing them closer together. This shortens the outer surface of the annulus and causes it to first assume a nearly straight position, then curve backward until it quite or nearly becomes doubled on itself.

The sporangium opens between the lip cells on the front, and the lateral walls of the sporangium are torn directly across. The greater mass of spores are thus held in the upper end of the open sporangium, and when the annulus has nearly doubled on itself it suddenly snaps back again in position. While treating

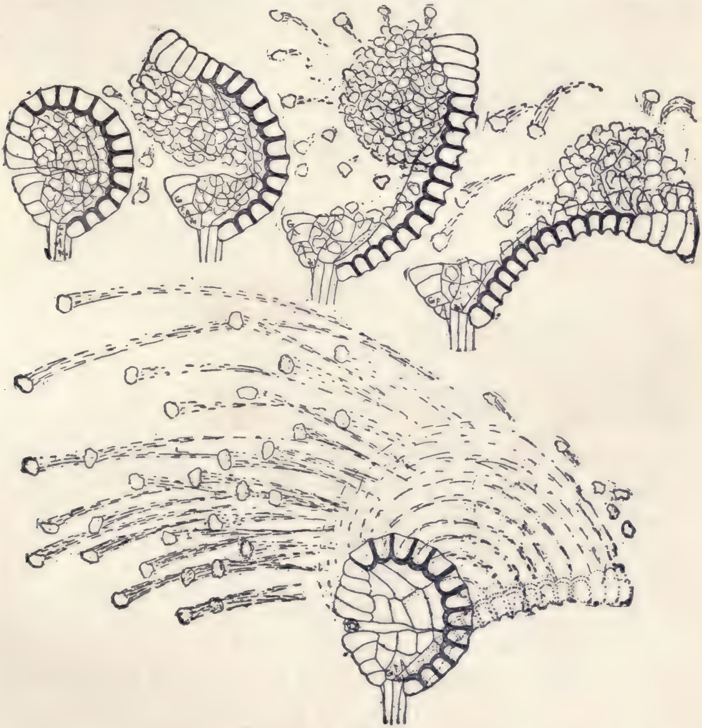


Fig. 138.
Dispersion of spores from sporangium of Aspidium acrostichoides, showing different stages in the opening and snapping of the annulus.

with the glycerine we can see all this movement take place. Each cell of the annulus acts independently, but often they all act in concert. When they do not all act in concert, some of them snap sooner than others, and this causes the annulus to snap in segments.

268. The movements of the sporangium can take place in old and dried material.—If we have no fresh material to study the sporangium with, we can use dried material, for the movements of the sporangia can be well seen in dried material, provided it was collected at about the time the sporangia are mature, that is at maturity, or soon afterward. We take some of the dry sporangia (or we may wash the glycerine off those which we have just studied) and mount them in water, and quickly examine them with a microscope. We notice that in each cell of the annulus there is a small sphere of some gas. The water which bathes the walls of the annulus is absorbed by some substance inside these cells. This we can see because of the fact that this sphere of gas becomes smaller and smaller until it is only a mere dot, when it disappears in a twinkling. The water has been taken in under such pressure that it has absorbed all the gas, and the farther pressure in most cases closes the partly opened sporangium more completely.

269. The annulus can snap several times.—Now we should add glycerine again and draw out the water, watching the sporangia at the same time. We see that the sporangia which have opened and snapped once will do it again. And so they may be made to go through this operation several times in succession. We should now note carefully the annulus, that is, after the sporangia have opened by the use of glycerine. So soon as they have snapped in the glycerine we can see those minute spheres of gas again, and since there was no air on the outside of the sporangia, but only glycerine, this gas must, it is reasoned, have been given up by the water before it was all drawn out of the cells.

This movement of the annulus is a very effective provision for the mechanical distribution of the spores of ferns. The successive periods of wet and dry weather, or of damp or dry air, when the sporangia are mature serves to open the sporangium successively so that all the spores are scattered. This opening and closing probably goes on for a considerable time

after the dispersal of the spores; for material which has been dried for nearly twenty years has been used to show the snapping of the sporangium. The sporangia which remain on the leaves out-doors snap so often with the changes of the weather that the annulus is literally worn out.

Synopsis.

- Fern plant.
  - Root.
  - Stem.
  - Leaf.
    - Sterile leaves.
      - Petiole.
      - Lamina.
    - Fertile leaves, i.e., spore-bearing leaves.
      - Petiolc.
      - Lamina.
        - Fruit dots (sorus).
        - Indusium when present.
        - Sporangium.
        - Spores.

Material and apparatus.—Entire plants with the root stock, and some of the leaves with the fruit dots, may be preserved dry.

Portions of the leaves with the fruit dots, at the time the spores have just matured, but have not opened, may be preserved in 2% formalin. If possible, for the study of the opening of the sporangia obtain fresh material of the mature sporangia. They may often be obtained from greenhouses, and the leaf with the fruit dots before the sporangia have opened should be immersed in water as they are taken to the laboratory or in a very damp moist chamber, since the dry air of the room soon causes them to open and scatter the spores.

Apparatus, the same as in Chapter XXIV.

Glycerine.

CHAPTER XXVII.

FERNS—CONCLUDED.

THE SEXUAL STAGE OF FERNS.

270. THIS CHAPTER IS LARGELY FOR READING AND FOR REFERENCE, though the teacher should endeavor to give demonstrations of the sexual organs, in their position on the under side of the prothallium, and also sections to show the structure. Prepared slides may be purchased for the purpose if it is not possible to obtain the material for making them. Prothallia may be grown by sowing the spores of ferns collected during the summer and saved in paper bags. If possible, a gardener in a greenhouse where ferns are grown should be consulted. Where they cannot be grown, it may be possible to purchase the prothallia also for study. When these can be obtained the student should make as careful an examination of the prothallium as possible before they are examined under the microscope.

Exercise 54.

271. Prothallium.—Note the small size of the prothallium, its form, color, delicate texture. Upon the under side observe the rhizoids. At which end of the prothallium are the rhizoids attached? With the aid of a hand lens can you see any other projections from the under side of the prothallium? Where are they located? Sketch a prothallium showing the under side and all the parts that can be seen with the aid of a hand lens.

Demonstration 39.

272. To show the sexual organs attached to the under surface of the prothallium. Mount a prothallium with the under side uppermost in water on a glass slip, and prepare for examination with the microscope. Study with the low power of the microscope. Near the sinus of the heart-shaped

prothallium look for conic projections, the archegonia (see fig. 139) ; among the rhizoids look for smaller but more numerous, rounded projections, the antheridia. Compare the prothallium with the thallus of marchantia. Sketch a prothallium under the low power of the microscope if there is time.

Among the prothallia search for some showing the young fern plant.

Demonstration 40.

273. To show the structure of the sexual organs of ferns. Make thin sections lengthwise of the prothallium along the middle line. These are best made in collodion or paraffin, and mounted in balsam. If the teacher has not the apparatus for making them, prepared slides may be purchased for the demonstration. Let the pupils sketch the structure of an antheridium and archegonium (see paragraphs 281 and 282), and name the parts.

If there is time and material the teacher may demonstrate young prothallia soon after the germination of the spores.

The following description of the sexual stage of ferns is for reading and study.

For further studies on the gametophyte phase of ferns, see the author's larger "Elementary Botany," Chapter XXVI.

274. Sexual stage of ferns.—We now wish to see what the sexual stage of the ferns is like. Judging from what we have found to take place in the liverworts and mosses we would infer that the form of the plant which bears the sexual organs is developed from the spores. This is true, and if we should examine old decaying logs, or decaying wood in damp places in the near vicinity of ferns, we would probably find tiny, green, thin, heart-shaped growths, lying close to the substratum. These are also found quite frequently on the soil of pots in plant conservatories where ferns are grown. Gardeners also in conservatories usually sow fern spores to raise new fern plants, and usually one can find these heart-shaped growths on the surface ot the soil where they have sown the spores. We may call the gardener to our aid in finding them in conservatories, or even in growing them for us if we cannot find them outside. In some cases they may be grown in an ordinary room by keeping the surfaces where they are growing moist, and the air also moist, by placing a glass bell jar over them.

275. The prothallium.—In fig. 139 is shown one of these growths enlarged. Upon the under side we see numerous thread-like outgrowths, the rhizoids, which attach the plant to the substratum, and which act as organs for the absorption of nourishment. The sexual organs are borne on the under side also. This heart-shaped, flattened, thin, green plant is the

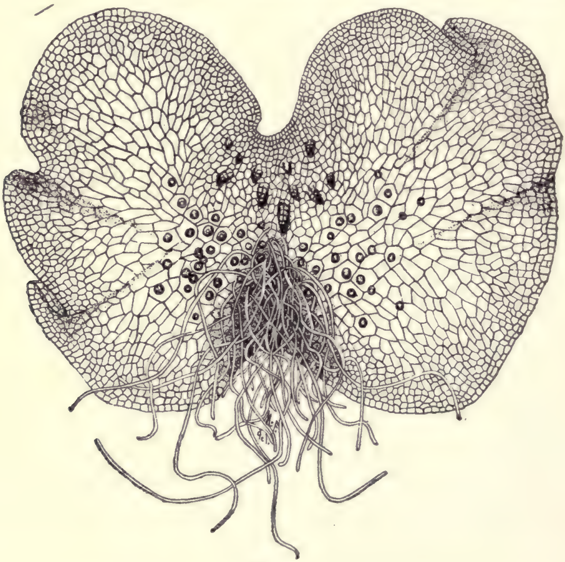


Fig. 139.
Prothallium of fern, under side, showing rhizoids, antheridia scattered among and near them, and the archegonia near the sinus.

prothallium of ferns, and we should now give it more careful study, beginning with the germination of the spores.

276. Spores.—We can easily obtain material for the study of the spores of ferns. The spores vary in shape to some extent. Many of them are shaped like a three-sided pyramid. One of these is shown in fig. 140. The outer wall is roughened, and on one end are three elevated ridges which radiate from a given point. A spore of the Christmas fern is shown in fig. 141. The outer wall here is more or less winged.

277. Germination of the Spores.—After the spores have been sown for about one week to ten days we should mount a few in water for examination with the microscope in order to study the early stages. If germination has begun, we find that here and there are short slender green threads, in many cases attached to brownish bits, the old walls of the spores. Often one will sow the sporangia along with the spores, and in such cases there may be found a number of spores still within the old sporangium wall that are germinating, when they will appear as in fig. 142.

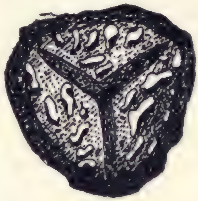


Fig. 140.
Spore of Pteris serrulata showing the three-rayed elevation along the side of which the spore wall cracks during germination.

278. Protonema. — These short green threads are called *protonemal* threads, or *protonema*, which means a *first thread*, and it here signifies that this short thread only precedes a larger growth of the same object. In figs. 142, 143 are shown several stages of germination of different spores. Soon after the short germ tube emerges from the crack in the spore wall, it divides by the formation of a cross-wall, and as it increases in length other cross-walls are formed. But very early in its growth we see that a slender outgrowth takes place from the cell nearest the old spore wall. This slender thread is colorless, and is not divided into cells. It is the first rhizoid, and serves both as an organ of attachment for the thread, and for taking up nutriment.

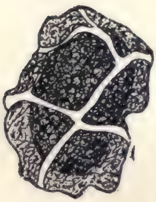


Fig. 141.
Spore of Aspidium acrostichoides with winged exospore.

279. Growth of the prothallium.—Very soon, if the sowing has not been so crowded as to prevent the young plants from obtaining nutriment sufficient, we will see that the end of this protonema is broadening, as shown in fig. 143. This is done by the formation of the cell walls in different directions. It now continues to grow in this way, the end becoming broader and broader, and new rhizoids are formed from the under surface

of the cells. The growing point remains at the middle of the advancing margin, and the cells which are cut off from either side, as they become old, widen out. In this way the "wings," or margins of the little, green, flattened body, are

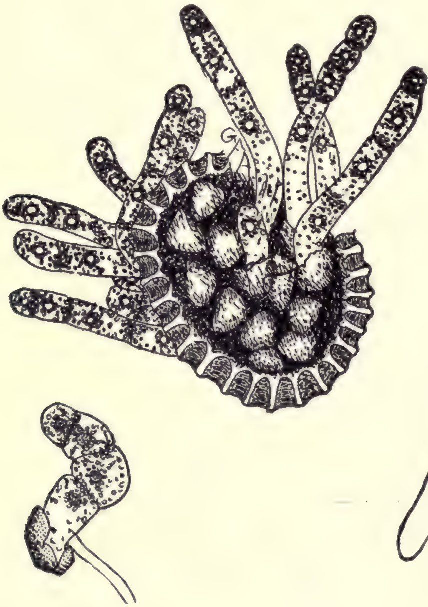


Fig. 142.
Germinating spores of Pteris aquilina still in the sporangium.

Fig. 143.
Young prothallium of a fern (niphobolus).

in advance of the growing point, and the object is more or less heart-shaped, as shown in fig. 139. Thus we see how the prothallium of ferns is formed.

280. Sexual organs of ferns.—If we take one of the prothallia of ferns which have grown from the sowings of fern spores, or one of those which may be often found growing on the soil of pots in conservatories, mount it in water on a slip, with the

under side uppermost, we can then examine it for the sexual organs, for these are borne in most cases on the under side.

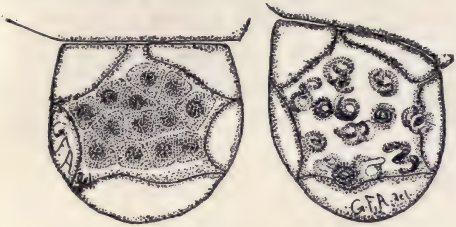


Fig. 144.
Section of antheridia showing sperm cells, and spermatozoids in the one at the right.

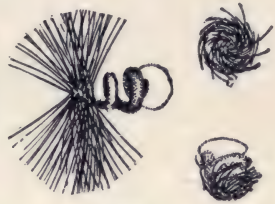


Fig. 145.
Different views of spermatozoids; in a quiet condition; in motion (Adiantum concinnum).

281. Antheridia.—If we search among the rhizoids we see small rounded elevations as shown in figure 139 scattered over this portion of the prothallium. These are the antheridia. If the prothallia have not been watered for a day or so, we may have an opportunity of seeing the spermatozoids coming out of the antheridium, for when the prothallia are freshly placed in water the cells of the antheridium absorb water. This presses on the contents of the antheridium and bursts the cap cell if the antheridium is ripe, and all the spermatozoids are shot out. We can see here that each one is shaped like a screw, with the coils at first closed. But as the spermatozoid begins to move this coil opens somewhat and by the vibration of the long cilia which are on the smaller end it whirls away. In such preparations one may often see them spinning around for a long while, and it is only when they gradually come to rest that one can make out their form.

Fig. 146.
Archegonium of fern. Large cell in the venter is the egg, next is the ventral canal cell, and in the canal of the neck are two nuclei of the canal cell.

282. Archegonia.—If we now examine closely, on the thicker part of the under surface of the prothallium, just back of the

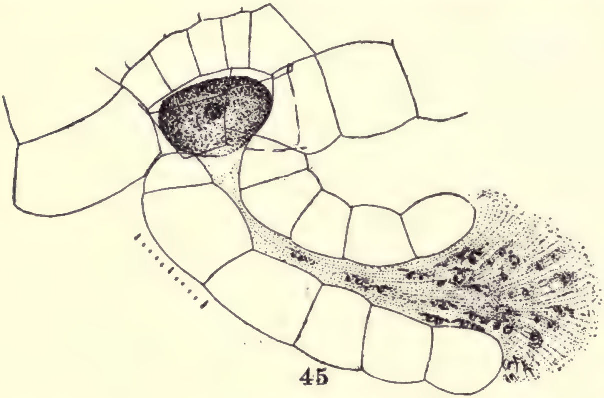


Fig. 147.
Mature and open archegonium of fern (Adiantum cuneatum) with spermatozoids making their way down through the slime to the egg.

"sinus," we may see longer stout projections from the surface of the prothallium. These are shown in fig. 139. They are the archegonia. One of them in longisection is shown in fig. 146. It is flask-shaped, and the broader portion is sunk in the tissue of the prothallium. The egg is in the larger part. The spermatozoids when they are swimming around over the under surface of the prothallium

Fig. 148.
Fertilization in a fern (marattia). *sp*, spermatozoid fusing with the nucleus of the egg. (After Campbell.)

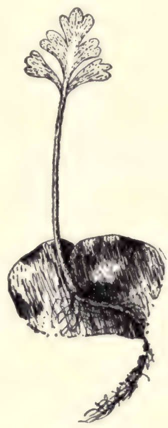


Fig. 149.
Young plant of Pteris serrulata still attached to prothallium.

come near the neck, and here they are caught in the viscid substance which has oozed out of the canal of the archegonium. From here they slowly swim down the canal, and finally one sinks into the egg, fuses with the nucleus of the latter, and the egg is then fertilized. It is now ready to grow and develop into the fern plant. This brings us back to the sporophyte, which begins with the fertilized egg.

Synopsis.

Sexual stage. Prothallium. (Corresponds to the vegetative part of the liverwort and moss.)	Flattened, green, heart-shaped growth, with rhizoids underneath. Sexual organs, under side of prothallium. Antheridium. { Wall. Spermatozoids. Archegonium. { Wall. Egg.

Material and apparatus.—Prothallia of ferns, entire ; they are often found growing in soil of pots in greenhouses where ferns are grown. Or they may be grown by sowing the spores.

For demonstrations of the structure of the sexual organs the teacher can make sections, or permanent ones may be obtained from supply companies.

Apparatus, same as in Chapter XXIV.

CHAPTER XXVIII.

HORSETAILS (EQUISETINEÆ).

(*The field equisetum.*)

283. Equisetum is related to the ferns.—Among the relatives of the ferns are the horsetails, so called because of the supposed resemblance of the branched stems of some of the species to a horse's tail, as one might infer from the plant shown in fig. 154. They do not bear the least resemblance to the ferns which we have been studying. But then relationship in plants does not depend on mere resemblance of outward form, or of the prominent part of the plant.

The field equisetum (Equisetum arvense) is a good one to study. If desired another one may be used for comparison, the scouring rush, or shave grass (E. hyemale).

Exercise 55.

THE FIELD EQUISETUM.

284. Fertile shoots.—The material should show the underground stem. Note the underground stem, its branching, color ; the connection of the upright fertile shoot with it. Note the roots. What is the color of the fertile shoot ? Is there much chlorophyll ?

Observe the nodes (joints) of the stem, the membranous crown (leaves) around each node, the character of the margin of this crown. Study the internodes, note the marking into ridges and furrows. What is the relation of the ridges and furrows of one node with those of each adjacent node ? What is the relation of the points of the leaves with the ridges ? Sketch a fertile shoot.

285. The fruiting spike.—The fruiting spike at the end of the shoot. Observe the numerous disks which are also arranged in whorls. Tease off

some of these from the shoot. Note the short stalk ; how is this stalk attached? Describe the sacs underneath. (These are the spore-cases.)

Sketch a spore-bearing leaf.

If some of the spores are at hand which fall out of the spore-cases when the sporangia dry, examine them under a hand lens ; at the same time breathe upon them. What happens?

286. The sterile shoot.—Compare the sterile shoots with the fertile shoots. Note the leaves arranged in the same way, but smaller. Note the branching of the plant and the arrangement of the branches. Are there leaves on the branches? Describe them. Sketch a sterile shoot. What is the color of the sterile shoot? In what part of the plant does the chlorophyll lie? In what part of the plant does the process of starch formation (or photosynthesis) take place?

Compare the scouring rush (E. hyemale) if there is time.

Demonstration 41.

287. Spores and elaters.—Mount some of the spores of equisetum on a dry glass slip. Let each pupil examine them under the microscope, sketch and describe the form ; breathe lightly on them and watch the result.

288. The field equisetum. Fertile shoots.—Fig. 150 represents the common horsetail (Equisetum arvense). It grows in moist sandy or gravelly places, and the fruiting portion of the plant (for this species is dimorphic), that is the portion which bears the spores, appears above the ground early in the spring. It is one of the first things to peep out of the recently frozen ground. This fertile shoot of the plant does not form its growth this early in the spring. Its development takes place under the ground in the autumn, so that with the advent of spring it pushes up without delay. This shoot is from 10 to 20 *cm.* high, and at quite regular intervals there are slight enlargements, the nodes of the stem. The cylindrical portions between the nodes are the internodes. If we examine the region of the internodes carefully we note that there are thin membranous scales, more or less triangular in outline, and connected at their bases into a ring around the stem. Curious as it may seem, these are the leaves of the horsetail. The stem, if we examine it further, will be seen to possess numerous ridges

which extend lengthwise and which alternate with furrows. Further, the ridges of one node alternate with those of the internode both above and below. Likewise the leaves of one node alternate with those of the nodes both above and below.

Fig. 150. Portion of fertile plant of Equisetum arvense, showing whorls of leaves and the fruiting spike.

289. Sporangia.—The end of this fertile shoot we see possesses a cylindrical to conic enlargement. This is the *fertile spike*, and we note that its surface is marked off into regular areas if the spores have not yet been disseminated. If we dissect off a few of these portions of the fertile spike, and examine one of them with a low magnifying power, it will appear like the fig. 151. We see here that the angular area is a disk-shaped body, with a stalk attached to its inner surface, and with several long sacs projecting from its inner face parallel with the stalk and surrounding the same. These elongated sacs are the *sporangia*, and the disk which bears them, together with the stalk which attaches it to the stem axis, is the *sporophyll*, and thus belongs to the leaf series. These sporophylls are borne in close whorls on the axis.

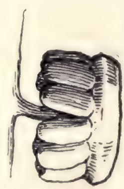


Fig. 151. Peltate sporophyll of equisetum (side view) showing sporangia on under side.

290. Spores.—When the spores are ripe the tissue of the sporangium becomes dry, and it cracks open and the spores fall out. In fig. 152 we see that the spore is covered with a very singular coil which lies close to the wall. When the spore dries this uncoils and thus rolls the spore about. Merely breathing upon these spores is sufficient to make them perform very curious evolutions by the twisting of these four coils which are attached to one place of the wall. They are formed by the splitting up of an outer wall of the spore.

291. Sterile shoot of the common horsetail.—When the spores are ripe they are soon scattered, and then the fertile

Fig. 152.
Spore of equisetum with elaters coiled up.

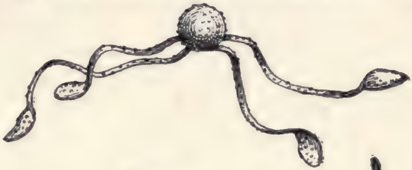


Fig. 153.
Spore of equisetum with elaters uncoiled.

shoot dies down. Soon afterward, or even while some of the fertile shoots are still in good condition, sterile shoots of the plant begin to appear above the ground. One of these is shown in fig. 154. This has a much more slender stem and is provided with numerous branches. If we examine the stem of this shoot, and of the branches, we shall see that the same kind of leaves are present and that the markings on the stem are similar. Since the leaves of the horsetail are membranous and not green, the stem is green in color, and here the process of starch formation goes on. These green shoots live for a great part of the season, building up material which is carried down into the underground stems, where it goes to supply the forming fertile shoots in the fall. On digging up some of these plants we see that the underground stems are often of great extent, and that both fertile and sterile shoots are attached to one and the same.

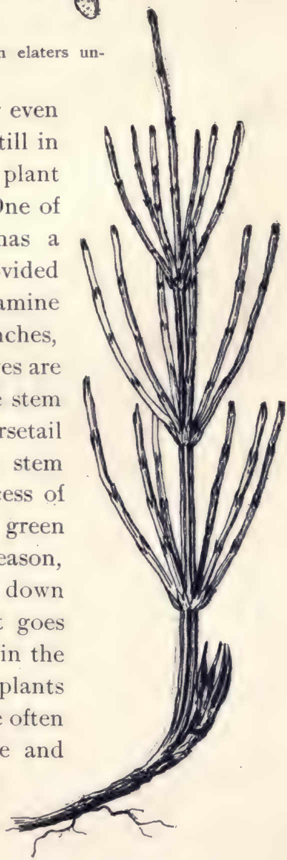


Fig. 154.
Sterile plant of horsetail (Equisetum arvense).

292. The scouring rush, or shave grass.—Another common species of horsetail in the Northern States grows

on wet banks, or in sandy soil which contains moisture along railroad embankments. It is the scouring rush (E. hyemale), so called because it was once used for polishing purposes. This plant like all the species of the horsetails has underground stems. But unlike the common horsetail, there is but one kind of aerial shoot, which is green in color and fertile. The shoots range as high as one meter or more, and are quite stout. The new shoots which come up for the year are unbranched, and bear the fertile spike at the apex. When the spores are ripe the apex of the shoot dies, and the next season small branches may form from a number of the nodes.

293. Gametophyte of equisetum.—The spores of equisetum have chlorophyll when they are mature, and they are capable of germinating as soon as mature. The spores are all of the same kind as regards size, just as we found in the case of the ferns. But they develop prothallia of different sizes, according to the amount of nutriment which they obtain. Those which obtain but little nutriment are smaller and develop only antheridia, while those which obtain more nutriment become larger, more or less branched, and develop archegonia. This character of an independent prothallium (gametophyte) with the characteristic sexual organs, and the also independent sporophyte, with spores, shows the relationship of the horsetails with the ferns. We thus see that these characters of the reproductive organs, and the phases and fruiting of the plant, are more essential in determining relationships of plants than the mere outward appearances.

Synopsis.

The field equisetum.
- Root.
- Shoot.
  - Underground stem or rhizome.
  - Sterile shoot (branched, green, later than the fertile shoot).
  - Fertile shoot (early in the spring).
    - Stem with nodes and internodes, crown of membranous pointed leaves at the nodes.
    - Fruiting spike.
      - Whorls of peltate spore-bearing leaves.
        - Several sporangia on inner side of the sporophylls.
        - Sporangium contains
          - Spores each with four elaters.

(The prothallium is not described here.)

Material and apparatus.—Entire plants including the underground root stock may be preserved dry. The fertile shoots appear earlier, and should be collected just as they are appearing from the ground ; the sterile shoots should be collected later when they are well formed.

Apparatus, the same as in Chapter XXIV.

CHAPTER XXIX.

QUILLWORTS (ISOETES).

Exercise 56.

294. The isoetes plant.—Sketch an entire plant. Only the leaves (resembling "quills") and the roots can be seen. Note the relation of the leaves, how they overlap. Remove a few. Describe and sketch the form. Note the thickened base, its shape like a spoon.

Upon the inner side of the thickened base note the circular depression of a different texture. This is the spore-case. Note the thin overlapping membrane around the edge of the spore-case. Just above the sporangium note the small appendage. Observe the thin outer wall of the spore-case; that through this in many cases the large spores can be seen in many of the spore-cases, especially the outer ones.

Section a plant longitudinally, or examine one that has been split into halves longitudinally, in order to see the attachment of the leaves, and to see the short stem. Note here also the spores in the spore-cases; also the cross-strands of tissue dividing the spore-cases into chambers.

Tease open several of the sporangia to expose the spores. Note the large spores in some; the small spores in others.

Demonstration 42.

295. Two kinds of spores.—Spores of each kind may be mounted in water for demonstration. Let each pupil sketch and describe one of each kind. It is an important thing for the student to know one of the fern-like plants which bear the two kinds of spores, as it helps one to understand the two different kinds of spores in the pines and flowering plants.

296. Habit of isoetes.—The quillworts, as they are popularly called, are very curious plants. They grow in wet marshy places. They receive their name from the supposed resemblance of the

leaf to a quill. Fig. 155 represents one of these quillworts (Isoetes engelmannii). The leaves are the prominent part of the plant, and they are about all that can be seen except the roots, without removing the leaves. Each leaf, it will be seen, is long and needle-like, except the basal part, which is expanded, not very unlike, in outline, a scale of an onion. These expanded basal portions of the leaves closely overlap each other, and the very short stem is completely covered at all times. Fig. 157 is from a longitudinal section of a quillwort. It shows the form of the leaves from this view (side view), and also the general outline of the short stem, which is triangular. The stem is therefore a very short object.

Fig. 155.
Isoetes, mature plant.

297. Sporangia of isoetes.—If we pull off some of the leaves of the plant we see that they are somewhat spoon-shaped as in fig. 156. In the inner surface of the expanded base we note a circular depression which seems to be of a different texture from the other portions of the leaf. This is a *sporangium*. Beside the spores on the inside of the sporangium, there are strands of sterile tissue which extend across the cavity. This is peculiar to isoetes of all the members of the class of plants to which the ferns belong, but it will be re-

membered that sterile strands of tissue are found in some of the liverworts in the form of elaters.

298. Microspores and macrospores.—The spores of isoetes are of two kinds, small ones (microspores) and large ones (macrospores). When one kind of spore is borne in a sporangium usually all in that sporangium are of the same kind, so that certain sporangia bear microspores, and others bear macrospores. But

Fig. 156.
Base of leaf of isoetes, showing sporangium with macrospores. (Isoetes engelmannii).

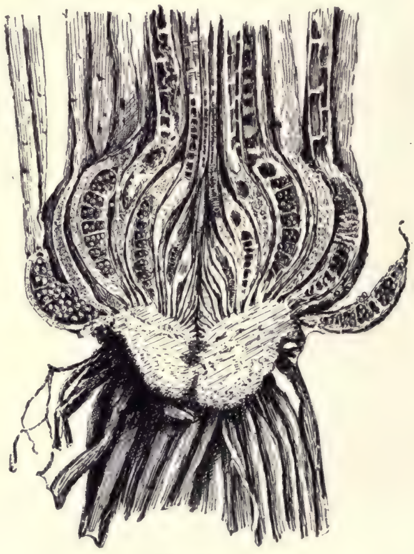


Fig. 157.
Section of plant of Isoetes engelmanii, showing cup-shaped stem, and longitudinal sections of the sporangia in the thickened bases of the leaves.

it is not uncommon to find both kinds in the same sporangium. When a sporangium bears only microspores the number is much greater than when one bears only macrospores.

For a discussion of the club mosses (lycopodium and selaginella) and for a comparison of the ferns and fern-like plants, see the author's larger "Elementary Botany," Chapters XXVIII and XXX.

Synopsis.

Quillwort (Isoetes).
- Root.
- Short stem.
  - Leaves long, quill-like.
    - Sporangium in base of each leaf.
      - Some sporangia with small spores.
      - Some sporangia with large spores.

(The prothallium is not described here.)

Material.—Entire plants, some dried, and others preserved in alcohol.

CHAPTER XXX.

GYMNOSPERMS.

THE WHITE PINE.

Exercise 57.

299. The long shoots of the pine.—Take a branch which shows the long shoots, and several whorls of branches. Note the terminal shoot; if in early summer observe the scale-like leaves borne on the long shoots. Note that the branches belong to the long shoots, and that they are arranged in a whorl at the end of each year's growth. (This whorl is a false one.)

300. The short branches.—On the long shoots note the short branches ending in a tuft of long green needle-like leaves. Note the short brownish scale-like leaves on the short shoots below where the needles are attached. In early spring if there are any pines in the vicinity note the growth of the long shoots, and the colorless scale leaves on them, and the appearance of the new green leaves on the new short shoots. How long do the green leaves remain on a pine?

Exercise 58.

301. Mature cones.—Note the form of the cone, the scales spread apart when dry. (Before the seeds are ripe the scales closely overlap.) Note the arrangement of the scales in spirals. Remove a few scales. Note the seeds attached to the inner lower end of the scale, unless they have split off.

Sketch the form of a scale showing the seeds attached. Sketch a detached seed, showing the wing-like appendage which splits off from the inner part of the scale.

302. Young female cones.—Note the small size as compared with the mature cones. Observe that the scales have the same arrangement as in the mature cones. Sketch one. If you have an opportunity to see the young cones on the tree just at the time of pollination, make a note of their position, and the position of the scales. Some time after pollination note the position of the cones, say any time during the summer, and the position of

the scales. Why are the cones and scales in these different positions at these different times?

Remove several scales and study them carefully. Sketch the form of one showing both sides. Upon the outer side note a small appendage (cover scale ; if there are spruces at hand compare the difference in size of the cover scale of the pine and spruce).

Upon the inner side note the two oval bodies at the two lower angles. These are the *ovules*, and correspond to the large sporangia. Note carefully a forceps-like appendage at the lower end of each ovule ; a little depression between them. This is the place where the pollen is drawn up after pollination.

Observe that the seeds are developed at this same point on the scale, and that the seed is formed from a later growth of the ovule and its parts.

Observe also that the ovules and seeds of the pine are naked, that is, they are exposed. From this character the name of the *gymnosperms*, or naked seed plants, is derived.

Exercise 59.

303. The male cones.— Observe the large clusters of the male flowers, several cones collected together. Sketch a cluster. Sketch a separate cone. Note that the cone is made up of an axis and scales as in the female cone, but the scales are different in form, Remove several of the scales. Note the form.

Upon the under side note the two strong convexities. Cut across scale, and note that there are two sacs situated here. These sacs are the spore-cases (small sporangia). The fine granules which escape are the small spores, or pollen.

If you have an opportunity when the pollen is ripe on a pine tree, jar the tree to see the clouds of pollen "dust" escape. When the sacs on the under side of the scale open in drying, note the position of the slit. Sketch such an open scale.

Demonstration 43.

304. Pollen grains.—Mount a few of the pollen grains in water for examination with the microscope. Let each pupil observe, and sketch a pollen grain. Observe the two large air sacs on either side of the pollen grain. Of what use are these air sacs to the pollen? Do insects pollinate the pines, or are they wind pollinated?

If it is desired to demonstrate the prothallium, archegonia, and fertilization in the pine, the teacher can either prepare or purchase slides for the purpose. See the author's larger "Elementary Botany," Chapters XXI and XXII, for further studies of the gymnosperms, and for fertilization, etc.

305. General aspect of the white pine.—The white pine (Pinus strobus) is found in the Eastern United States. In favorable situations in the forest it reaches a height of about 50 meters (about 160 feet), and the trunk a diameter of over 1 meter. In well-formed trees the trunk is straight and towering; the branches where the sunlight has access and the trees are not crowded, or are young, reaching out in graceful arms, form a pyramidal outline to the tree. In old and dense forests the lower branches, because of lack of sunlight, have died away, leaving tall, bare trunks for a considerable height.

306. The long shoots of the pine.—The branches are of two kinds. Those which we readily recognize are the long branches, so called because the growth in length each year is considerable. The terminal bud of the long branches, as well as of the main stem, continues each year the growth of the main branch or shoot; while the lateral long branches arise each year from buds which are crowded close together around the base of the terminal bud. The lateral long branches of each year thus appear to be in a whorl. The distance between each false whorl of branches, then, represents one year's growth in length of the main stem or long branch.

307. The dwarf shoots of the pine.—The dwarf branches are all lateral on the long branches, or shoots. They are scattered over the year's growth, and each bears a cluster of five long, needle-shaped, green leaves, which remain on the tree for several years. At the base of the green leaves are a number of chaff-like scales, the previous bud scales. While the dwarf branches thus bear green leaves, and scales, the long branches bear only thin scale-like leaves which are not green.

308. Spore-bearing leaves of the pine.—The two kinds of spore-bearing leaves of the pine, and their close relatives, are so different from anything which we have yet studied, and are so unlike the green leaves of the pine, that we would scarcely recognize them as belonging to this category. Indeed there is great uncertainty regarding their origin.

309. Male cones, or male flowers.—The male cones are borne in clusters as shown in fig. 158. Each compact, nearly cylindrical, or conical mass is termed a cone, or flower, and each arises in place of a long lateral branch. One of these cones is

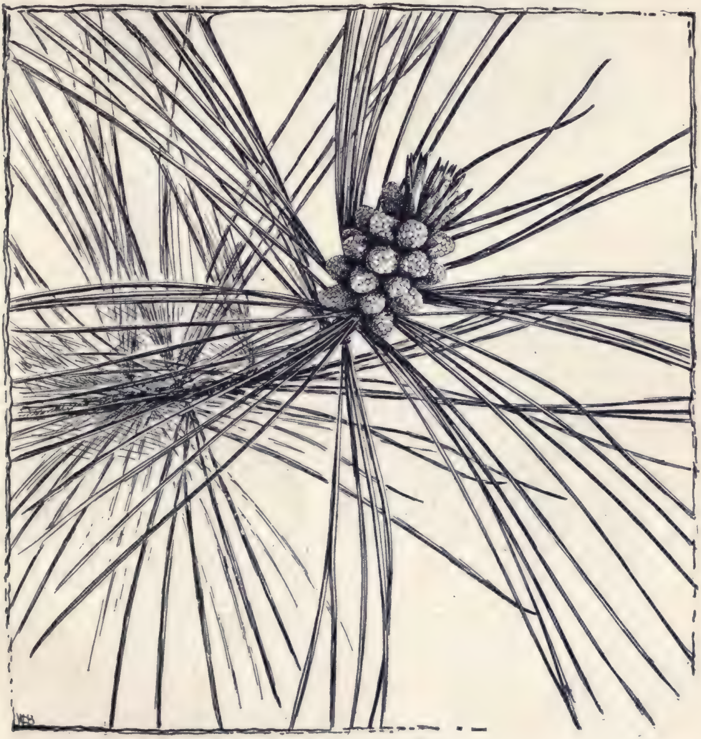


Fig. 158.
Spray of white pine showing cluster of male cones just before the scattering of the pollen.

shown considerably enlarged in fig. 159. The central axis of each cone is a lateral branch, and belongs to the stem series. The stem axis of the cone can be seen in fig. 160. It is completely covered by stout, thick, scale-like outgrowths. These scales are obovate in outline, and at the inner angle of the

upper end there are several rough, short spines. They are attached by their inner lower angle, which forms a short stalk

Fig. 159.
Staminate cone of white pine, with bud scales removed on one side.

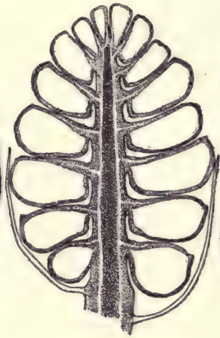


Fig. 160.
Section of staminate cone showing sporangia.

Fig. 161.
Two sporophylls removed, showing opening of sporangia.

or petiole, and continues through the inner face of the scale as a "midrib." What corresponds to the lamina of the scale-like leaf bulges out on each side below and makes the bulk of the scale. These prominences on the under side are the sporangia (micro-sporangia). There are thus two sporangia on a sporophyll (micro-sporophyll). When the spores (microspores), which here are usually called pollen grains, are mature each sporangium, or anther locule, splits down the middle as shown in fig. 161, and the spores are set free.

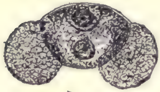


Fig. 162.
Pollen grain of white pine.

310. Microspores of the pine, or pollen grains.—A mature pollen grain of the pine is shown in fig. 162. It is a queer-looking object, possessing on two sides an air sac, formed by the upheaval of the outer coat of the spore at these two points. When the pollen is mature, the moisture dries out of the scale (or stamen, as it is often called here) while it ripens. When a limb, bearing a cluster of male cones, is jarred by the hand, or

by currents of air, the split suddenly opens, and a cloud of pollen bursts out from the numerous anther locules. The pollen is thus borne on the wind and some of it falls on the female flowers.

311. Form of the mature female cone.—A cluster of the white-pine cones is shown in fig. 163. These are mature, and the scales have

Fig. 163.
White pine, branch with cluster of mature cones shedding the seed. A few young cones four months old are shown on branch at the left. Drawn from photograph.

Fig. 164.
Mature cone of white pine at time of scattering of the seed, nearly natural size.

spread as they do when mature and becoming dry, in order that the seeds may be set at liberty. The general outline of the cone is lanceolate, or long oval, and somewhat curved. It measures about 10–15 *cm* long. If we remove one

of the scales, just as they are beginning to spread, or before the

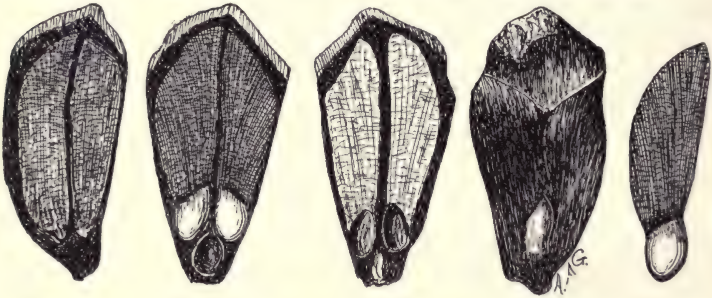


Fig. 165. Sterile scale. Seeds undeveloped.

Fig. 166. Scale with well-developed seeds.

Fig. 167. Seeds have split off from scale.

Fig. 168. Back of scale with small cover scale.

Fig. 169. Winged seed free from scale.

Figures 165–169 —White pine showing details of mature scales and seed.

seeds have scattered, we shall find the seeds attached to the upper surface at the lower end. There are two seeds on each scale, one at each lower angle. They are ovate in outline, and shaped somewhat like a biconvex lens. At this time the seeds easily fall away, and may be freed by jarring the cone. As the seed is detached from the scale a strip of tissue from the latter is peeled off. This forms a "wing" for the seed. It is attached to one end and is shaped something like a knife blade. On the back of the scale is a small appendage known as the cover scale.

Fig. 170.
Female cones of the pine at time of pollination, about natural size.

312. Formation of the female pine cone.—The female flowers begin their development rather late in the spring of the year. They are formed from terminal buds of the higher branches of the tree. In this way the cone may terminate the main shoot of a branch, or of the lateral shoots in a whorl. After growth has proceeded for some time in the spring, the terminal portion begins to assume the ap-

pearance of a young female cone or flower. These young female cones, at about the time that the pollen is escaping from the anthers, are long ovate, measuring about 6–10 *mm* long. They stand upright as shown in fig. 170.

313. Form of a "scale" of the female flower. — If we remove one of the scales from the cone at this stage we can better study it in detail. It is flattened, and oval in outline, with a stout "rib," if it may be so called, running through the middle line and terminating in a point. The scale is in two parts as shown in fig. 173, which is a view of the under side. The small "outgrowth" which appears as an appendage is the cover scale, for while it is smaller in the pine than the other portion, in some of the relatives of the pine it is larger than its mate, and being on the outside, covers it. (The inner scale is sometimes called the ovuliferous scale, because it bears the ovules.)

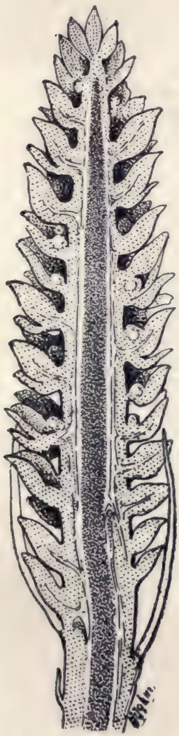


Fig. 171.
Section of female cone of white pine, showing young ovules (macrosporangia) at base of the ovuliferous scales.

Fig. 172.
Scale of white pine with the two ovules at base of ovuliferous scale.

Fig. 173.
Scale of white pine seen from the outside, showing the cover scale.

314. Ovules, or macrosporangia, of the pine.—At each of the lower angles of the scale is a curious oval body with two curved, forceps-like processes at the lower and

smaller end. These are the macrosporangia, or, as they are called in the higher plants, the ovules. These ovules, as we see, are in the positions of the seeds on the mature cones. In fact the wall of the ovule forms the outer coat of the seed, as we will later see.

315. Pollination.—At the time when the pollen is mature the female cones are still erect on the branches, and the scales, which during the earlier stages of growth were closely pressed against one another around the axis, are now spread apart. As the

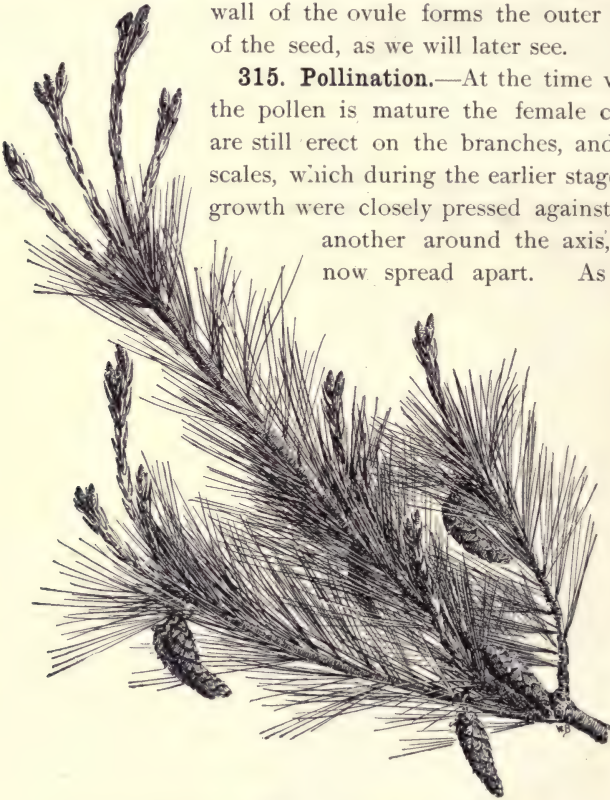


Fig. 174.
Branch of white pine showing young female cones at time of pollination on the ends of the branches, and one-year-old cones below, near the time of fertilization.

clouds of pollen burst from the clusters of the male cones, some of it is wafted by the wind to the female cones. It is here caught in the open scales, and rolls down to their bases, where some of it falls between these forceps-like processes at the lower end of the ovule. At this time the ovule has exuded a drop of

a sticky fluid in this depression between the curved processes at its lower end. The pollen sticks to this, and later, as this viscid substance dries up, it pulls the pollen close up in the depression against the lower end of the ovule. This depression is thus known as the *pollen chamber*.

Now the open scales on the young female cone close up again, so tightly that water from rains is excluded. What is also very curious, the cones, which up to this time have been standing erect, so that the open scale could catch the pollen, now turn so that they hang downward. This more certainly excludes the rains, since the overlapping of the scales forms a shingled surface. Quantities of resin are also formed in the scales, which exudes and makes the cone practically impervious to water.

The female cone now slowly grows during the summer and autumn, increasing but little in size during this time. During the winter it rests, that is, ceases to grow. With the coming of spring, growth commences again and at an accelerated rate. The increase in size is more rapid. The cone reaches maturity in September. We thus see that nearly eighteen months elapse from the beginning of the female flower to the maturity of the cone, and about fifteen months from the time that pollination takes place.

Material.—Several branches of the pine showing the long shoots and whorls of branches. (These should be had in the laboratory if the tree cannot be studied in the open. If fresh branches cannot be had, preserve them dry.)

Mature cones collected in August just before the seeds fall away. Branches with the female cones, collected from the top of the tree, in early summer (June), preserve in alcohol.

Branches with the clusters of male cones collected late in May or early in June just before the pollen is scattered. Preserve in alcohol.

Sections to show the female prothallium, archegonium, and fertilization can be made by the teacher, or they may be purchased of supply companies.

Dissecting microscope, or tripod lens; dissecting needles.

CHAPTER XXXI.

MORPHOLOGY OF THE ANGIOSPERMS: TRILLIUM; DENTARIA.

Exercise 60.

316. Trillium.—Note the general habit of the plant; the short, thick, underground stem, which is perennial; the roots attached to this; the scale leaves at the anterior end around the base of the flowering stem. Note the flowering stem; the whorl of three green leaves on it, and the terminal flower. Observe that there are no roots attached to the flowering stem. Is the flowering stem perennial?

Exercise 61.

317. Flower of trillium.—Observe the difference in the parts of the flower; two whorls of leaf-like parts on the outside. Take these up in order, beginning at the outside.

Outer whorl (calyx); note the resemblance of each member of the calyx to the leaf. How do they compare in number with the whorl of leaves on the stem? Sketch one. Each one is a *sepal*.

318. Corolla the second whorl.—Is there any resemblance between the parts of the corolla and a leaf of trillium? How do the parts compare as to form and number with the leaves? Sketch one. Each part of the corolla is a *petal*.

319. Third and fourth whorl (andrœcium).—Note here that there are six members composing these two whorls, three in each. Is there any resemblance between these and the leaves? Did you ever see any of these members (stamens) partly changed to petals or leaves in trillium? Did you ever see any of them partly changed in other flowers? in the water lily for example. Examine a water lily when you have an opportunity. Look for these changes in other plants when you have an opportunity.

Sketch a stamen, and name the parts, the slender stalk (filament), the more expanded part (anther) with four long sacs (anther locules, or sacs);

if they have just opened observe the great quantity of yellow "dust." These are the pollen grains, or the small spores. (The anther sacs then must be the small sporangia.)

320. The inner whorl (gynœcium).—Note that the structure in the centre of the trillium flower ends in three slender points; cut across the larger part of this object below. Note that it has three chambers. What does this suggest? What do you find attached to the inner walls of these chambers? They are the ovules. Sketch a cross-section. Is there any relation between the three parts of this structure (pistil) and leaves? What is this relation? Compare the mature fruit of trillium (if at hand) with the pistil and ovules.

Description of Trillium.

321. General appearance.—As one of the plants to illustrate this group we may take the wake-robin, as it is sometimes called, or trillium. There are several species of this genus in the United States; the commonest one in the eastern part is the "white wake-robin" (Trillium grandiflorum). This occurs in or near the woods. A picture of the plant is shown in fig. 175. There is a thick, fleshy, underground stem, or rhizome as it is usually called. This rhizome is perennial, and is marked by ridges and scars. The roots are quite stout and possess coarse wrinkles. From the growing end of the rhizome each year the leafy, flowering stem arises. This is 20–30 *cm.* (8–12 inches) in height. Near the upper end is a whorl of three ovate leaves, and from the centre of this rosette rises the flower stalk, bearing the flower at its summit.

322. Parts of the flower. Calyx.—Now if we examine the flower we shall see that there are several leaf-like structures. These are arranged also in threes just as are the leaves. First there is a whorl of three, pointed, lanceolate, green, leaf-like members, which make up the *calyx* in the higher plants, and the parts of the calyx are *sepals*, that is, each leaf-like member is a *sepal*. But while the sepals are part of the flower, so called, we easily recognize them as belonging to the *leaf series*.

323. Corolla.—Next above the calyx is a whorl of white or pinkish members, in Trillium grandiflorum, which are also leaf-

like in form, and broader than the sepals, being usually somewhat broader at the free end. These make up what is the *corolla* in the higher plants, and each member of the corolla is a *petal*. But while they are parts of the flower, and are not green, their form and position would suggest that they also belong to the leaf series.

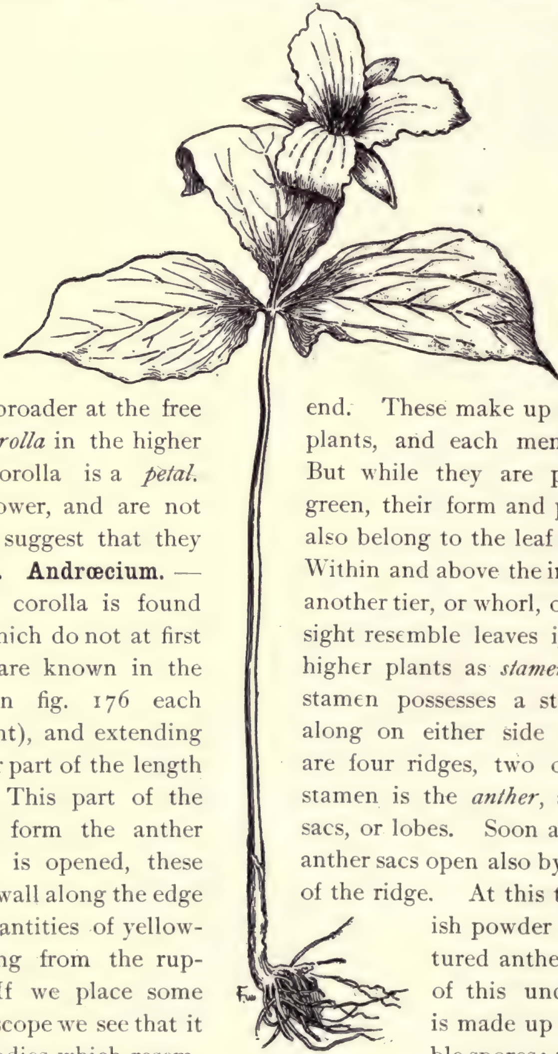


Fig. 175.
Trillium grandiflorum.

324. Andrœcium. — Within and above the insertion of the corolla is found another tier, or whorl, of members which do not at first sight resemble leaves in form. They are known in the higher plants as *stamens*. As seen in fig. 176 each stamen possesses a stalk (= filament), and extending along on either side for the greater part of the length are four ridges, two on each side. This part of the stamen is the *anther*, and the ridges form the anther sacs, or lobes. Soon after the flower is opened, these anther sacs open also by a split in the wall along the edge of the ridge. At this time we see quantities of yellowish powder or dust escaping from the ruptured anther locules. If we place some of this under the microscope we see that it is made up of minute bodies which resemble spores; they are rounded in form, and the outer wall is spiny.

They are in fact spores, the microspores of the trillium, and here, as in the gymnosperms, are better known as *pollen*.

325. The stamen a sporophyll.—Since these pollen grains are the spores, we would infer, from what we have learned of the ferns and gymnosperms, that this

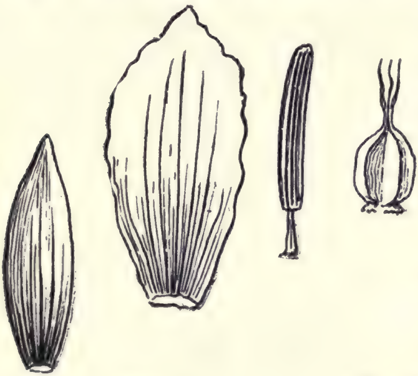


Fig. 176.
Sepal, petal, stamen, and pistil of Trillium grandiflorum.

Fig. 177.
Trillium grandiflorum, with the compound pistil expanded into three leaflike members. At the right these three are shown in detail.

member of the flower which bears them is a sporophyll; and this is the case. It is in fact what is called the *microsporophyll*. Then we see also that the anther sacs, since they enclose the spores, would be the sporangia (microsporangia). From this it is now quite clear that the stamens belong also to the leaf series. They are just six in number, twice the number found in a whorl of leaves, or sepals, or corolla. It is believed, therefore, that there are two whorls of stamens in the flower of trillium.

326. Gynœcium.—Next above the stamens and at the centre of the flower is a stout, angular, ovate body which terminates in three long, slender, curved points. This is the pistil, and at

present the only suggestion which it gives of belonging to the leaf series is the fact that the end is divided into three parts, the number of parts in each successive whorl of members of the flower. If we cut across the body of this pistil and examine it with a low power we see that there are three chambers or cavities, and at the junction of each the walls suggest to us that this body may have been formed by the infolding of the margins of three leaf-like members, the places of contact having then become grown together. We see also that from the incurved margins of each division of the pistil there stand out in the cavity oval bodies. These are the *ovules*. Now the ovules, we have learned from our study of the gymnosperms, are the *sporangia* (here the macrosporangia). It is now more evident that this curious body, the pistil, is made up of three leaf-like members which have fused together, each member being the equivalent of a sporophyll (here the macrosporophyll). This must be a fascinating observation, that plants of such widely different groups and of such different grades of complexity should have members formed on the same plan and belonging to the same series of members, devoted to similar functions, and yet carried out with such great modifications that at first we do not see this common meeting ground which a comparative study brings out so clearly.

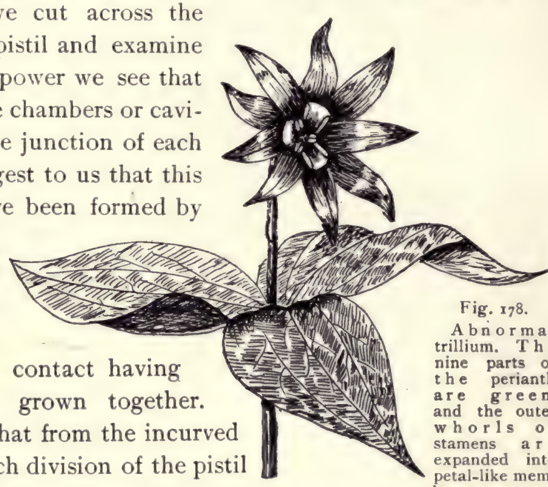


Fig. 178. Abnormal trillium. The nine parts of the perianth are green, and the outer whorls of stamens are expanded into petal-like members.

Fig. 179. Transformed stamen of trillium showing anther locules on the margin.

327. Transformations of the flower of trillium.—If anything more were needed to make it clear that the parts of the flower

of trillium belong to the leaf series we could obtain evidence from the transformations which the flower of trillium sometimes presents. In fig. 178 is a sketch of a flower of trillium, made from a photograph. One set of the stamens has expanded into petal-like organs, with the anther sacs on the margin. In fig. 177 is shown a plant of Trillium grandiflorum in which the pistil has separated into three distinct and expanded leaf-like structures, all green except portions of the margin.

Exercise 62.

328. Toothwort (dentaria).—Note the general habit of the plant; the rather long, slender, smooth, fleshy, underground, perennial root stock (stem); the rudimentary leaves; the roots; the growing end some distance ahead of the point where the annual flowering shoot arises; compare with trillium in this respect.

The flowering annual shoot; note the slender, smooth stem, the two opposite leaves which are three divided (trifoliate), the open raceme of flowers terminating the shoot.

Exercise 63.

329. The flower.—Compare the parts of the flower with the leaves. The flowers should be collected before all of them are open, since the sepals fall away quite easily. Note that the flower parts are in twos or multiples of two, while in trillium the parts are in threes or multiples of three. In each case the number of parts in a whorl is the same as the number of leaves in a whorl, so that this strengthens the view of the parts of the flower being homologous with the leaves.

Illustrate and describe the different members of the flower. The pistil here is also a compound pistil.

If there is time compare with other flowers like the toothwort, as the shepherd's purse, mustard, etc.

Description of the Toothwort.

330. General appearance.—For another study we may take a plant which belongs to another division of the higher plants, the common "pepper root," or "toothwort" (Dentaria diphylla) as it is sometimes called. This plant occurs in moist

woods during the month of May, and is well distributed in the northeastern United States. A plant is shown in fig. 180. It has a creeping underground rhizome, whitish in color, fleshy, and with a few scales. Each spring the annual flower-bearing stem rises from one of the buds of the rhizome, and after the ripening of the seeds, dies down.

The leaves are situated a little above the middle point of the stem. They are opposite and the number is two, each one

Fig. 181.
Flower of the toothwort (Dentaria diphylla).

Fig. 180.
Toothwort (Dentaria diphylla).

being divided into three dentate lobes, making what is called a compound leaf.

331. Parts of the flower.—The flowers are several, and they are borne on quite long stalks (pedicels) scattered over the terminal portion of the stem. We should now examine the parts of the flower, beginning with the calyx. This we can see, looking at the under side of some of the flowers, possesses four scale-like sepals, which easily fall away after the opening of the flower. They do not resemble leaves so much as the sepals of trillium, but they belong to the leaf series, and there are two pairs in the set of four. The corolla also possesses four petals, which are more expanded than the sepals and are whitish in color. The stamens are six in number, one pair lower than the others, and also shorter. The filament is long in proportion to the anther, the latter consisting of two lobes or sacs, instead of four as in trillium. The pistil is composed of two carpels, or leaves fused together. So we find in the case of the pepper root that the parts of the flower are in twos, or multiples of two. Thus they agree in this respect with the leaves; and while we do not see such a strong resemblance between the parts of the flower here and the leaves, yet from the presence of the pollen (microspores) in the anther sacs (microsporangia) and of ovules (macrosporangia) on the margins of each half of the pistil, we are, from our previous studies, able to recognize here that all the members of the flower belong to the leaf series.

332. In trillium and in the pepper root we have seen that the parts of the flower in each apparent whorl are either of the same number as the leaves in a whorl, or some multiple of that number. This is true of a large number of other plants, but it is not true of all. The trillium and the dentaria were selected as being good examples to study first, to make it very clear that the members of the flower are fundamentally leaf structures, or rather that they belong to the same series of members as do the leaves of the plant.

Material.—Entire plants of trillium and dentaria in flower, with root stock. Specimens either fresh or dried. Entire flowers of both plants when they cannot be obtained at the right season, may be preserved in advance in formalin. A sufficient number should be prepared, depending on the number of pupils in the class. Mature fruit may also be preserved in formalin or alcohol. It will be useful to have entire plants of trillium collected in late autumn, in the winter, or early spring before the flower stalk rises above the ground, in order to see the condition in which the flower passes the winter.

CHAPTER XXXII.*

PROTHALLIUM AND SEXUAL ORGANS OF FLOWERING PLANTS.

333. The stamens and pistils are not the sexual organs.—Before the sexual organs and sexual processes in plants were properly understood it was customary for botanists to speak of the stamens and pistils of flowering plants as the sexual organs. Some of the early botanists, a century ago, found that in many plants the seed would not form unless first the pollen from the stamens came to be deposited on the stigma of the pistil. A little further study showed that the pollen germinated on the stigma and formed a tube which made its way down through the pistil and into the ovule.

This process, including the deposition of the pollen on the stigma, was supposed to be fertilization, the stamen was looked on as the male sexual organ, and the pistil as the female sexual organ. We have found out, however, by further study, and especially by a comparison of the flowering plants and the lower plants, that the stamens and pistils are not the sexual organs of the flower.

334. The stamens and pistils are spore-bearing leaves.—The stamen is the spore-bearing leaf, and the pollen grains are not unlike spores; in fact they are the small spores of the angiosperms. The pistil is also a spore-bearing leaf, the ovule the sporangium, which contains the large spore called an *embryo sac*. In the ferns we know that the spore germinates and produces the green heart-shaped prothallium. The prothallium bears the sexual

* This chapter is for reading and reference, but if the teacher desires to give demonstrations of the germinating pollen grain, and of the embryo sac, the following memorandum on material will be found of assistance.

organs. Now the fern leaf bears the spores and the spore forms the prothallium. So it is in the flowering plants. The stamen bears the small spores—pollen grains—and the pollen grain

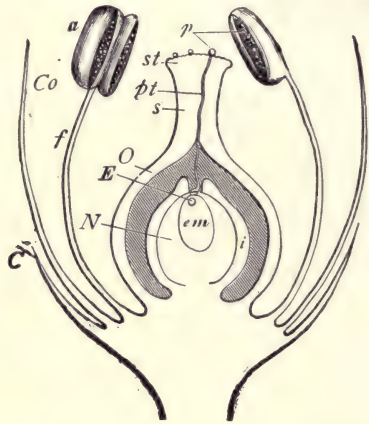


Fig. 182.

Diagrammatic section of a flower. *Ke*, calyx; *K*. corolla; *f*, the filament, and *a*, the anther, of the stamen; *p*, pollen-cells, some in the anther, others on the stigma; *F*, the ovary, surmounted by the style, *g*, and the stigma, *n* (this ovary contains one ovule, which has a single coat, *i*, enclosing the ovule-body, *S*); *em*, the embryo-sac; *E*, germ-cell; *ps*, a pollen-tube penetrating the style, and reaching the germ-cell through the micropyle of the ovule.

forms the prothallium. The prothallium in turn forms the sexual organs. The process is in general the same as it is in the ferns, but with this special difference: the prothallium and the sexual organ of the flowering plants are very much reduced.

335. The male prothallium is reduced to the pollen grain. —In fact the pollen grain is male prothallium and sexual organ all in one, so reduced has it become. A young pollen grain of trillium is shown in fig. 183. It has two cells. The entire pollen grain may be considered the antheridium, the larger cell representing the wall while the smaller cell is the generative cell. The latter corresponds to the central cell of the fern antheridium. In the angiosperms it divides to form two *sperm cells*. These cor-

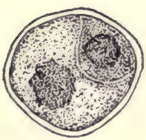


Fig. 183.

Nearly mature pollen grain of trillium. The smaller cell is the generative cell.

respond to the spermatozoids, though they are not motile. Sometimes the sperm cells are formed within the pollen grain. At other times they are only formed after the pollen grain has germinated. In fig. 184 is a germinating pollen grain of peltandra, showing three nuclei. The generative cell has divided to form the two sperm cells.

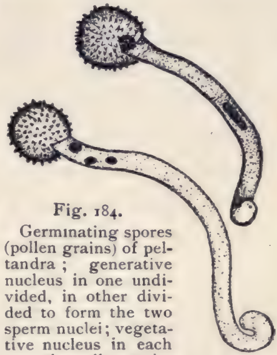


Fig. 184.
Germinating spores (pollen grains) of peltandra; generative nucleus in one undivided, in other divided to form the two sperm nuclei; vegetative nucleus in each near the pollen grain.

336. The embryo sac is the female prothallium.—Now while the small spore (= the pollen grain) escapes usually from the anther, the larger spore (= embryo sac), borne in the ovule on the pistil, never escapes completely from the ovule, and only rarely protrudes part way. Inside of the nucellus, which is the central part of the ovule, a sac is formed which contains several nuclei. It is the embryo sac, or large spore, as shown in the diagram. It is also the female prothallium. One of these nuclei is the egg nucleus, but the prothallium is so reduced that there is no archegonium wall. The egg itself is perhaps the reduced archegonium.

337. Fertilization.—When the pollen tube grows down the pistil and into the embryo sac in the ovule, as shown in the diagram (fig. 182), one of the sperm nuclei which it bears unites with the egg nucleus of the embryo sac. This is *fertilization.* The fertilized egg now grows to form the embryo. So the embryo is formed inside of the ovule. This is what makes the seed. The ovule with its coats contains the embryo. Since the embryo sac containing the egg does not escape from the ovule, the sperm cell must in some way be brought to it. This necessitates the transportation of the pollen from the stamen to the pistil. This transportation of the pollen from the stamen to the pistil is *pollination.* Botanists now usually distinguish in this way between pollination and fertilization.

338. Difference between organ and member.—While it is

not strictly correct then to say that the stamen is a sexual organ, or male organ, we might regard it as a *male member* of the flower, and we should distinguish between *organ* and *member*. It is an *organ* when we consider *pollen production*, but it is not a sexual organ. When we consider *fertilization* it is *not a sexual organ, but a male member* of the flower which bears the small spore.

The following table will serve to indicate these relations.

Stamen	= spore-bearing leaf = male member of flower.
Anther locule	= sporangium.
Pollen grain	= small spore = reduced male prothallium and sexual organ.

So the pistil is not a sexual organ, but might be regarded as the female member of the flower.

Pistil	= spore-bearing leaf = female member of flower.
Ovule	= sporangium.
Embryo sac	= large spore = female prothallium containing the egg.
The egg	= a reduced archegonium = the female sexual organ.

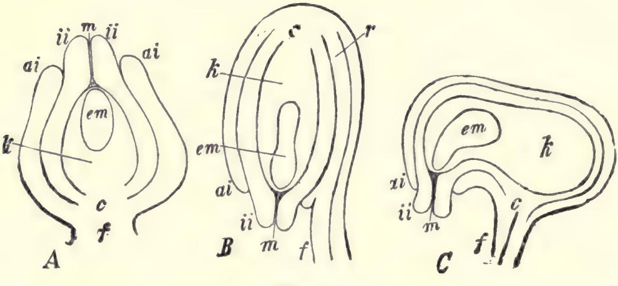


Fig. 185.

A, represents a straight (orthotropus) ovule of polygonum; *B*, the inverted (anatropous) ovule of the lily; and *C*, the right angled (campylotropus) ovule of the bean. *f*, funicle; *c*, chalaza; *k*, nucellus; *ai*, outer integument; *ii*, inner integument; *m*, micropyle; *em*, embryo sac.

339. Parts of the ovule.—In fig. 185 are represented three different kinds of ovules, which depend on the position of the

ovule with reference to its stalk. The funicle is the stalk of the ovule, the hilum is the point of attachment of the ovule with the ovary, the raphe is the part of the funicle in contact with the ovule in inverted ovules, the chalaza is the portion of the ovule where the nucellus and the integuments merge at the base of the ovule, and the micropyle is the opening at the apex of the ovule where the coats do not meet.

340. In the pines and other gymnosperms the male and female prothallium, as regards structure and development, are intermediate between those of the higher plants and the ferns, but they are nevertheless much reduced. For a full discussion of the prothallium and sexual organs of the gymnosperms and angiosperms see the author's larger "Elementary Botany," Chapters XXXI, XXXII, and XXXIV, and for pollination, see Chapter L.

Material.—To show the male and female prothallium of angiosperms. Pollen grains of several species may be germinated in a weak solution of sugar in water, and these studied with the aid of the microscope, to see the pollen tube.

The female prothallium (embryo sac in different stages) can be obtained by making sections of ovules just before and after fertilization. The lily is a good one to use, since there are many ovules standing at right angles to the pistil. Cross-sections of the pistil afford many good sections of the ovules where they are carefully made. Permanent slides can be purchased of supply companies.

CHAPTER XXXIII.

SEEDS AND SEEDLINGS.

I. Seeds.

This chapter is for reading and reference.

341. Parts of the seed.—The seed consists of the embryo surrounded by the ripened ovule and certain secondary growths. Following fertilization as the embryo is forming in the embryo sac, a new growth of cells is formed also within the embryo sac but surrounding the embryo. This is called the *endosperm.* The young embryo derives some of its nutriment from the endosperm. In some seeds the nucellus (central part of the ovule) forms nutritive tissue, which may be consumed during the ripening of the seed, or in some seeds a portion of it remains outside of the endosperm, as *perisperm.*

342. Outer parts of the seed.—While the embryo is forming within the ovule and the growth of the endosperm is taking place, where this is formed, other correlated changes occur in the outer parts of the ovule, and often in adjacent parts of the flower. These unite in making the "seed," or the "fruit." Especially in connection with the formation of the seed a new growth of the outer coat, or integument, of the ovule occurs, forming the outer coat of the seed, known as the *testa*, while the inner integument is absorbed. In some cases the inner integument of the ovule also forms a new growth, making an inner coat of the seed (rosaceæ). In still other cases neither of the integuments develops into a testa, and the embryo sac lies in contact with the wall of the ovary. Again an additional

envelope grows up around the seed; an example of this is found in the case of the red berries of the "yew" (taxus), the red outer coat being an extra growth, called an *aril.*

In the willow and the milkweed an aril is developed in the form of a tuft of hairs. (In the willow it is an outgrowth of the funicle, = stalk of the ovule, and is called a funicular aril; while in the milkweed it is an outgrowth of the micropyle, = the open end of the ovule, and is called a micropylar aril.)

343. Increase in size during seed formation.—Accompanying this extra growth of the different parts of the ovule in the formation of the seed is an increase in the size, so that the seed is often much greater in size than the ovule at the time of fertilization. At the same time parts of the ovary, and in many plants, the adherent parts of the floral envelopes, as in the apple; or of the receptacle, as in the strawberry; or in the involucre, as in the acorn; are also stimulated to additional growth, and assist in making the fruit.

In the pine not only the ovular coat grows to form the outer coat of the seed, the entire "scale" increases greatly in size, and when the fruit is mature, a portion of this scale splits off forming a "wing" to the seed (see fig. 169).

344. Endosperm in the ripe seed.—In many seeds when they are ripe there is still a large amount of the endosperm surrounding the embryo (albuminous seeds). This is the case in the violet, as shown in fig. 186. Other examples of this kind are found in the buttercup family, the grasses, the lily, palm, jack-in-the-pulpit, etc. When the seed germinates this endosperm is used as food by the embryo.

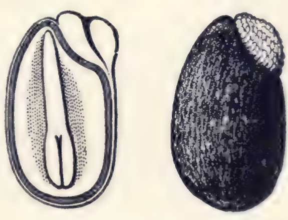


Fig. 186.

Seed of violet, external view, and section. The section shows the embryo lying in the endosperm.

345. Endosperm absent in the ripe seed.—In many other plants all of the endosperm is consumed by the embryo during its growth in the formation of the seed. This is the case in the

rose family, crucifers, composites, willows, oaks, legumes, etc., as in the acorn, the bean, pea, and others. In some, as in the bean, a large part of the nutrient substance passing from the endosperm into the embryo is stored in the cotyledons for use during germination (exalbuminous seeds).

346. Synopsis of the seed.

The seed.
- *Ripened ovule.*
  - Aril, rarely present.
  - Ovular coats (one or two usually present), the *testa.*
  - *Funicle* (stalk of ovule), *raphe* (portion of funicle when bent on to the side of ovule), *micropyle*, *hilum* (scar where seed was attached to ovary).
  - *Remnant of the nucellus* (central part of ovule); sometimes nucellus remains as *Perisperm* in some albuminous seeds.
- *Endosperm*, present in albuminous seeds.
- *Embryo* within surrounded by endosperm when this is present, or by the remnant of nucellus, and by the ovular coats which make the *testa*.

See figures for parts of the ovule.

II. Seedlings.

(For reading, unless exercises 1–4 have not yet been employed. In that case those exercises should be taken up now.)

347. Additional studies on seedlings.—In beginning our studies of the life processes of plants we used a number of seedlings. We found it necessary to learn something about the parts of the seedling, and in fact about the parts of mature plants in dealing with the functions which the members of the plant perform. Now, however, we are dealing more strictly with the parts of the plant in respect to the form of the member, and its value as showing relationship among plants. So that studies of seeds and seedlings is a part of our study of the form characters in the morphology of the angiosperms. Even if one choses to complete the practical study of the seedling under the head of the life processes of plants, one should now take the seeds and seedlings again into account in recognizing their relation to the new

theme, and in learning the value of characters which aid us in assigning plants to their proper categories.

348. The three seedlings to be studied.—For this reason some of the illustrations of seedlings are introduced here, as well as an account of their germination, and the means by which they obtain food stored in the seed. In connection with this reading the pupil can refer back to the plants studied in exercises 1–4, and the teacher is at liberty to introduce here exercises, if that seems desirable to further illustrate the subject where there is an abundance of time. Three seedlings are selected to illustrate the theme here; the common garden bean, the castor-oil bean, and the jack-in-the-pulpit.

349. The common garden bean.—The seed coats are nearly filled with the two large cotyledons, which form the larger part of the embryo. After the beans have been well soaked if one is split lengthwise the young root and stem with the small leaves will be seen lying between the cotyledons at one side. There is no endosperm here now, since it was all used up in the growth of the embryo, and a large part of its substance was stored up in the cotyledons. As the seed germinates the young plant gets its first food from that stored in the cotyledons. The part of the stem between the cotyledons and the root (called the hypocotyl in all seedlings) elongates, so that the cotyledons are lifted from the soil. The hypocotyl is the part of the stem here which becomes strongly curved, and the large cotyledons are dragged out of the soil as shown in fig. 187. The outer coat becomes loosened, and at last slips off completely. The plumule (the young part of the stem with the leaves) is now pushing out from between the cotyledons. As the cotyledons are coming out of the ground the first pair of leaves rapidly enlarge, so that before the stem has straightened up there is a considerable leaf surface for the purpose of starch formation. The leaves are at first clasped together, but as the stem becomes erect they are gradually parted and come to stand out nearly in a horizontal position. Fig. 187 shows the different positions.

As the cotyledons become exposed to the light they assume a green color. Some of the stored food in them goes to nourish the embryo during germination, and they therefore become smaller, shrivel somewhat, and at last fall off.

350. The castor-oil bean.—This is not a true bean since it belongs to a very different family of plants (euphorbiaceæ). In the germination of this seed a very interesting comparison can be made with that of the garden bean. As the "bean" swells the very hard outer coat generally breaks open at the free end and slips off at the stem end. The next coat within, which is also hard and shining black, splits open at the opposite end, that

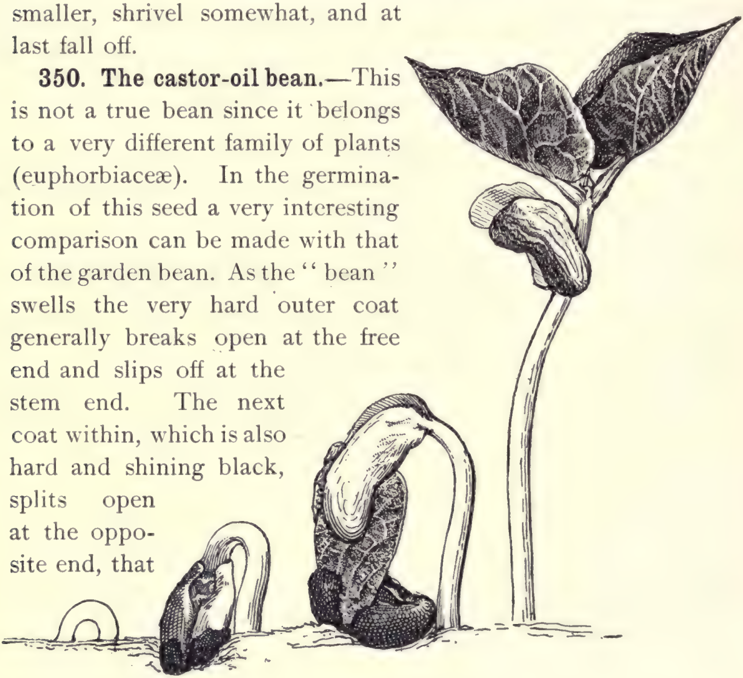


Fig. 187.

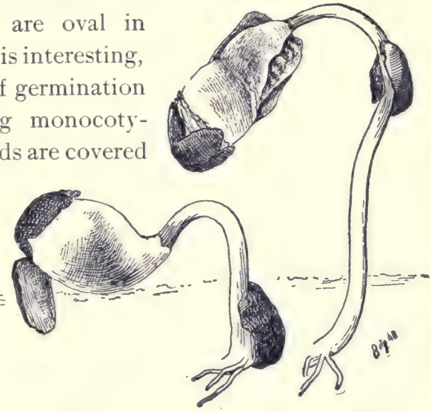
How the garden bean comes out of the ground. First the looped hypocotyl, then the cotyledons pulled out, next casting off the seed coat, last the plant erect, bearing thick cotyledons, the expanding leaves, and the plumule between them.

is at the stem end. It usually splits open in the form of three ribs. Next within the inner coat is a very thin, whitish film (the remains of the nucellus, and corresponding to the perisperm) which shrivels up and loosens from the white mass, the endosperm, within. In the castor-oil bean, then, the endosperm is not all absorbed by the embryo during the formation of the seed. As the plant becomes older we should note that the fleshy endosperm becomes thinner and thinner, and at

last there is nothing but a thin whitish film covering the green faces of the cotyledons. The endosperm has been gradually absorbed by the germinating plant through its cotyledons and used for food.

Arisæma triphyllum.

351. Germination of seeds of jack-in-the-pulpit. — The ovaries of jack-in-the-pulpit form large, bright red berries with a soft pulp enclosing one to several large seeds. The seeds are oval in form. Their germination is interesting, and illustrates one type of germination of seeds common among monocotyledonus plants. If the seeds are covered with sand, and kept in a moist place, they will germinate readily.



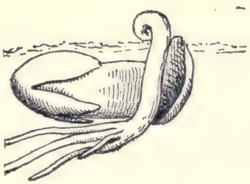


Fig. 188.
Germination of castor-oil bean.

352. How the embryo backs out of the seed.—The embryo lies within the mass of the endosperm; the root end, near the smaller end of the seed. The club-shaped cotyledon lies near the middle of the seed, surrounded firmly on all sides by the endosperm. The stalk, or petiole, of the cotyledon, like the lower part of the petiole of the leaves, is a hollow cylinder, and contains the younger leaves, and the growing end of the stem or bud. When germination begins, the stalk, or petiole, of the cotyledon elongates. This pushes the root end of the embryo out at the small end of the seed. The free end of the embryo

Fig. 189.

Seedlings of castor-oil bean casting the seed coats, and showing papery remnant of the endosperm.

Fig. 190.

Seedlings of jack-in-the-pulpit; embryo backing out of the seed.

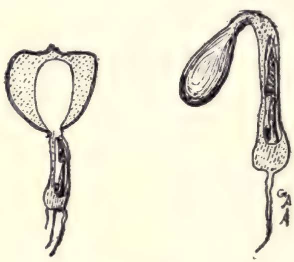


Fig. 191.

Section of germinating embryos of jack-in-the-pulpit, showing young leaves inside the petiole of the cotyledon. At the left cotyledon shown surrounded by the endosperm in the seed; at right endosperm removed to show the club-shaped cotyledon.

now enlarges somewhat, as seen in the figures, and becomes the bulb, or corm, of the baby jack. At first no roots are visible, but in a short time one, two, or more roots appear on the enlarged end.

353. Section of an embryo.—If we make a longisection of the embryo and seed at this time we can see how the club-shaped cotyledon is closely surrounded by the endosperm. Through the cotyledon, then, the nourishment from the endosperm is readily passed over to the growing embryo. In the hollow part of the petiole near the bulb can be seen the first leaf.

Fig. 192.
Seedlings of jack-in-the-pulpit, first leaf arching out of the petiole of the cotyledon.

Fig. 193.
Embryos of jack-in-the-pulpit still attached to the endosperm in seed coats, and showing the simple first leaf.

Fig. 194.
Seedling of jack-in-the-pulpit; section of the endosperm and cotyledon.

354. How the first leaf appears.—As the embryo backs out of the seed, it turns downward into the soil, unless the seed is

so lying that it pushes straight downward. On the upper side of the arch thus formed, in the petiole of the cotyledon, a slit appears, and through this opening the first leaf arches its way out. The loop of the petiole comes out first, and the leaf later, as shown in fig. 192. The petiole now gradually straightens up, and as it elongates the leaf expands.

355. The first leaf of the jack-in-the-pulpit is a simple one. —The first leaf of the embryo jack-in-the-pulpit is very different in form from the leaves which we are accustomed to see on mature plants. If we did not know that it came from the seed of this plant we would not recognize it. It is simple, that is it consists of one lamina or blade, and not of three leaflets as in the compound leaf of the mature plant. The simple leaf is ovate and with a broad heart-shaped base. The jack-in-the-pulpit, then, as trillium, and some other monocotyledonous plants which have compound leaves on the mature plants, have simple leaves during embryonic development. The ancestral monocotyledons are supposed to have had simple leaves. Thus there is in the embryonic development of the jack-in-the-pulpit, and others with compound leaves, a sort of recapitulation of the evolutionary history of the leaf in these forms.

CHAPTER XXXIV.

THE PLANT BODY AND SOME OF ITS MODIFICATIONS.

For reading and reference.

If it is desired to study the different kinds of stems, leaves, and roots, with their various modifications, the teacher can arrange some exercises based on the characters and examples given below in paragraphs 358–364.

356. The plant body.—In the simpler forms of plant life, as in spirogyra and many of the algæ and fungi, the plant body is not differentiated into parts. In many other cases the only differentiation is between the growing part and the fruiting part. In the algæ and fungi there is no differentiation into stem and leaf, though there is an approach to it in some of the higher forms. Where this simple plant body is flattened, as in the sea-wrack, or ulva, it is a *frond.* The Latin word for frond is *thallus*, and this name is applied to the plant body of all the lower plants, the algæ and fungi. The algæ and fungi together are sometimes called the *thallophytes*, or *thallus plants.* The word thallus is also sometimes applied to the flattened body of the liverworts. In the foliose liverworts and mosses there is an axis with leaf-like expansions. These are believed by some to represent true stems and leaves, by others to represent a flattened thallus in which the margins are deeply and regularly divided, or in which the expansion has only taken place at regular intervals.

357. Members of the plant body.—In the higher plants there is usually great differentiation of the plant body, though in

many forms, as in the duck-weeds, it is a frond. While there is great variation in the form and function of the members of the plant body, they are reducible to a few fundamental members. Some reduce these forms to three, the *root*, *stem*, and *leaf*, while others to two, the *root* and *shoot*, which is perhaps the better arrangement. Here the shoot is farther divided into stem and leaf, the leaf being a lateral outgrowth of the stem.

358. Synopsis of members of the plant in angiosperms.

- Higher plant.
  - Root.
  - Shoot.
    - Stem.
    - Leaf.
      - Foliage leaves.
      - Flower.
        - Perianth leaves.
        - Spore-bearing leaves with sporangia.
        - (Sporangia sometimes on shoot).

359. The parts of the plant body as members or organs.—The members of the plant body can be considered from several standpoints. We might study them from the standpoint of physiology, when the members would be regarded as organs for performing certain kinds of work. As organs for nutrition the leaves serve a purpose in transpiration and in starch formation. The roots and root hairs serve as organs for absorption of food from the soil. The bright petals of flowers often serve to attract insects which aid in cross-pollination. The stamens and pistils serve a purpose in the process of reproduction. The stems serve as support for the plant, for the transport of food materials, and for bearing the leaves and flowers. So in various modifications of the members purposes of protection, support, vegetative propagation, etc., are served.

In this sense the members of the plant body might be studied in Part I, in conjunction with the study of the means by which plants obtain their food.

From another standpoint we might consider the great variety of form, and the numerous modifications, as expressions of the forces of evolution, inheritance, relation to environment, etc. (see Ecology).

From still another standpoint they might be studied as indicating relationships. Their form, position, arrangement, etc., serve to characterize certain groups of individuals so that they can be distinguished from others.

The different forms of the members are usually designated by special names, but it is convenient to group them in the single series.

360. Stem Series.

Tubers, underground thickened stems, bearing buds and scale leaves; ex., Irish potato.

Root-stocks, underground, usually elongated, bearing scales or bracts, and a leafy shoot; ex., trillium, mandrake, etc. Root-stocks of the ferns bear expanded, green leaves.

Runners, slender, trailing, bearing bracts, and leafy stems as branches; ex., strawberry vines.

Corms, underground, short, thick, leaf bearing and scale bearing; ex., Indian turnip.

Bulbs, usually underground, short, conic, leaf and scale bearing; ex., lily.

Thorns, stout, thick, poorly developed branches with rudiments of leaves (scales); ex., hawthorn.

Tendrils, slender reduced stems.

Flower axes (see morphology of the angiosperms).

361. Leaf series.—Besides the foliage leaves, the following are some of their modifications:

Flower parts (see morphology of the angiosperms).

Bracts and scales, small, the former usually green (flower bracts), the latter usually chlorophylless. Bud scales are sometimes green.

Tendrils, modifications of the entire leaf (tendrils of the squash where the branched tendril shows the principal veins of the leaf), modification of the terminal pinnæ of the leaf (vetch), etc.

Spines (examples are found in the cacti, where the stem is enlarged and green, functioning as a leaf).

Other modifications occur as in the pitcher plant, insectivorous plants, etc.

362. The root shows less modification. Besides normal roots, which are fibrous in most small plants and stout in the larger ones, some of the modifications are found in fleshy roots, where nourishment is stored (ex., dahlia, sweet potato, etc.), aerial roots (ex., poison ivy, the twining form), aerial orchids, etc.

CHAPTER XXXV.

ARRANGEMENTS OF THE PARTS OF THE FLOWER.

This chapter is for reading and reference.

363. Relations of the parts of the flower.—In some plants the parts of the flower are distinct, and in others they are more or less united. Definite terms are used to indicate these relations of the parts of the flower. In trillium and dentaria which we have studied, all the sets, or whorls of parts, are *free;* i. e., no one floral set is *adherent* to another. The pistils make one set, the stamens another, the petals another, and the sepals another set. These sets are all *free* in their *insertion* on the receptacle of the flower. The receptacle of the flower is that portion of the stem where the flower parts are attached.

Further the parts of the calyx, corolla, and andrœcium are *distinct.* That is, the parts (sepals) of the calyx, for example, are not united together by their edges.

In the buttercup family, represented by the marsh marigold (figures 221, 222) all parts of the flower are both *free* and *distinct.*

364. Parts of the flower coherent.—But in both trillium and dentaria the parts of the gynœcium are *coherent*, i. e., the carpels (three in trillium and two in dentaria) are united into a single, compound pistil.

So in any set when the parts of that set are partly or completely united they are said to be *coherent.* The stamens are coherent by their anthers in the bell flower and in most of the flowers of the composite family, as in the aster (see fig. 242), sunflower, golden rod, etc.

In the morning-glory (fig. 195) the petals are *coherent*, forming a funnel-shaped corolla as shown in the figure. Such a corolla is also said to be *gamopetalous*. Where the sepals are coherent the calyx is *gamosepalous*. The morning-glory has a gamosepalous calyx also, though the sepals are only united near the base. In the morning-glory the petal parts can be distinguished, five in number, but they are not so prominent as in the bluet (fig. 196), where there are four prominent petal lobes.

Fig. 195. Morning-glory (Convolvulus sepium).

Sometimes the gamopetalous corolla is unequally lobed, when it may be "bilabiate," i.e., two-lipped as in the dead nettle (fig. 197), where there are three petal lobes in the lower lip and two petal lobes in the upper lip. Such a flower is also said to be *irregular*. The gamosepalous calyx may also be two-lipped.

365. Adherent.—In many plants one floral set is united with another, when such sets are *adherent*.

This is well shown in the flowers of the evening primrose, where the tubes of the gamopetalous corolla and gamosepalous calyx are united to form a long tube. This tube is again at its base adherent to the outer surface of the ovary, and above, the stamens are adherent to the throat of the tube (fig. 198).

366. Epigynous, perigynous, and hypogynous.—Where any portion of the calyx or corolla is adherent to the ovary, the

flower is said to be *epigynous*, as in the evening primrose. When the stamens or petals are borne on the calyx, the flower is said to be *perigynous*, or the stamens are said to be perigynous, as in the cherry (fig. 229), apple, etc. The flower is *hypogynous* when all the parts of the calyx, corolla, and andrœ-

Fig. 196.
The bluet (Houstonia cœrulea).

cium are free in their insertion, that is, when they are inserted on the receptacle, "under the pistil," since the pistil terminates the floral axis (example, the buttercup, etc.).

367. Floral Formula.—A formula is sometimes written to show at a glance the general points of agreement in the flower

among the members of a family or group. The floral formula of the lily family is written as follows: Calyx 3, Corolla 3,

Fig. 197.
Spray of dead-nettle (Lamium amplexicaule), leaves and flowers.

Fig. 198.
Section of flower of evening primrose.

Andrœcium 6(3–3), Gynœcium 3. The formula may be abbreviated thus: Ca3,Co3,A6(3 + 3),G3.

368. Floral diagram.—The relation of the parts of the flower on the axis are often represented by a diagram, as shown in figs. 221, 237, 244, etc.

CHAPTER XXXVI.

RELATIONSHIPS SHOWN BY FLOWER AND FRUIT.

369. Importance of the flower in showing kinships among the higher plants.—In the seed-bearing plants which we are now studying we cannot fail to be impressed with the general presence of what is called the flower.

While the spore-bearing members, as well as the floral envelopes, are thus grouped into "flowers," there is a great diversity in the number, arrangement, and interrelation of these members, as is suggested by our study of trillium and dentaria. And a farther examination of the flowers of different plants would reveal a surprising variety of plans. Nevertheless, if we compare the flower of trillium with that of a lily for example, or the flower of dentaria with that of the shepherd's purse (capsella), we shall at once be struck with the similarity in the plan of the flower, and in the number and arrangement of its members. This suggests to us that there may be some kinship, or relationship between the lily and trillium, and between the shepherd's purse and toothwort. In fact it is through the interpretation of these different plans that we are able to read in the book of nature of the relationship of these plants.

Note for Reference.

370. Arrangement of flowers.—The arrangement of the flowers (inflorescence) on the stem is important in showing kinships. The flowers may be scattered and distant from each other on the plant, or they may be crowded close together in

Fig. 199.
Spring beauty (Claytonia virginiana) flowers in a raceme.

spikes, catkins, heads, etc. Many of the flower arrangements are dependent on the manner of the branching of the stem. Some of the systems of branching are as follows:

371. I. Dichotomous branching.—True dichotomy (forking) does not occur in the shoots of flowering plants, but it does occur in some of the flower clusters.

372. II. Lateral branching.—Two main types.

Monopodial branching.—This occurs where the main shoot continues to grow more vigorously than the lateral branches which arise in succession around the main stem. Examples in shoots, horse-chestnut, pines (see chapter on pine). The inflorescence is termed *indefinite*, or *indeterminate inflorescence;* i.e., the flowers all arise from *lateral* buds, the main axis continuing to grow.

Raceme; lateral axes unbranched, youngest flowers near the terminal portion of long main axis; ex., choke-cherry, currant, spring beauty, etc.

Spike; main axis long, lateral unbranched axes with sessile and often crowded flowers; ex., plantain. Where the main axis is fleshy the spike forms a *spadix*, as in skunk's cabbage, Indian turnip, etc.; if the spike falls away after maturity of the flower or fruit it is a *catkin* or *ament* (willows, oaks, etc.).

Umbel; the main axis is shortened, and the stalked flowers appear to form terminal clusters or whorls, as in the parsley, carrot, parsnip, etc.

Head, or *capitulum;* the main axis is shortened and broadened, and bears sessile flowers, as in the sunflower, button-bush, etc.

Panicle; when the raceme has the lateral axes branched it forms a *panicle*, as in the oat. When the panicle is flattened it forms a *corymb*, as in the hawthorn.

Sympodial branching or cymose branching.—The branches, or lateral axes, grow more vigorously than the main axis, and form for the time false axes (form cymes).

The inflorescence is termed *cymose*, or *definite*, or *determinate* inflorescence because the growth of each axis is stopped by the formation of a flower.

Fig. 200.
Single umbel of the wild carrot.

1. Monochasium; only one lateral branch is produced from each relative or false axis.

Helicoid cyme; when the successive lateral branches always arise on the same side of the false axis, as in flower clusters of the forget-me-not.

Scorpioid cyme; when the lateral branches arise alternately on opposite sides of the false axis.

2. Dichasium; each relative, or false, axis produces two branches, often forming a false dichotomy. Examples in shoots are found in the lilac, where the shoot appears to have a dichotomous branching, though it is a false dichotomy.

Forking cyme; flower cluster of chickweed.

3. Pleiochasium; each relative, or false, axis produces more than two branches.

373. The fruit.—In some cases the single seed itself forms the fruit as is the case with nuts, sunflower seeds, etc. In other cases several seeds ripen inside of a single pistil as in the

bean pod, or in several pistils united as in the apple, to form the fruit. In the sunflower seed and the apple other parts of the flower are also united with the pistil in forming the fruit. The fruit of the angiosperms varies greatly, and often is greatly

Fig. 201.
Forget-me-not.

complicated. When the gynœcium is *apocarpous* (that is when the carpels are from the first *distinct*) the ripe carpels are separate, and each is a fruit. In the *syncarpous gynœcium* (when the carpels are united) the fruit is more complicated, and still more so when other parts of the flower than the gynœcium remain united with it in the fruit.

Pericarp; this is the part of the fruit which envelops the seed, and may consist of the carpels alone, or of the carpels and the adherent part of the receptacle, or calyx; it forms the wall of the fruit.

Endocarp and *exocarp.* If the pericarp shows two different layers, or zones, of tissue, the outer is the *exocarp,* and the inner the *endocarp,* as in the cherry, peach, etc.

Mesocarp; where there is an intermediate zone it is the *mesocarp*

I. Capsule (dry fruits). The capsule has a dry pericarp which opens (dehisces) at maturity. When the capsule is *syncarpous* the carpels may *separate* along the line of their union with each other longitudinally (*septicidal dehiscence*) as in the azalea, or rhododendron; or each carpel may *split down the middle line* (*loculicidal dehiscence*) as in fruit of iris, lily, etc.; or the carpels may open by pores (*poricidal dehiscence*), as in the poppy.

Follicle; a capsule with a single carpel which dehisces along the ventral, or upper, suture (*larkspur*, *peony*).

Legume or *pod;* a capsule with a single carpel which dehisces along both sutures (pea, bean, etc.).

Silique; a capsule of two carpels, which separate at maturity, leaving the partition wall persistent (tooth-wort, shepherd's-purse, and most others of the mustard family); when short it is a silicle or pouch.

Pyxidium or *pyxis;* the capsule opens with a lid (plantain).

II. Dry indehiscent fruits; do not dehisce or separate into distinct carpels.

Nuts; with a dry, hard pericarp.

Caryopsis; with one seed and a dry leathery pericarp (grasses).

Achene; with pericarp adherent to the seed (sunflower and other composites).

III. Schizocarp; a dry, several-loculed fruit, in which the carpels separate from each other at maturity but do not dehisce (umbelliferæ, mallow).

IV. Berry; endocarp and mesocarp both juicy (grape).

V. Pome; mesocarp and outer portion of endocarp soft and juicy, inner portion of endocarp papery (apple).

VI. Drupe, or stone fruit; endocarp hard and stony, exocarp soft and generally juicy (cherry, walnut); in the cocoanut the exocarp is soft and spongy.

CHAPTER XXXVII.

CLASSIFICATION (OR TAXONOMY).

374. Species.—It is not necessary for one to be a botanist in order to recognize, during a stroll in the woods where the trillium is flowering, that there are many individual plants very like each other. They may vary in size, and the parts may differ a little in form. When the flowers first open they are usually white, and in age they generally become pinkish. In some individuals they are pinkish when they first open. Even with these variations, which are trifling in comparison with the points of close agreement, we recognize the individuals to be of the *same kind,* just as we recognize the corn plants grown from the seed of an ear of corn as of the same kind. Individuals of the same kind, in this sense, form a *species.* The white wake-robin, then, is a species.

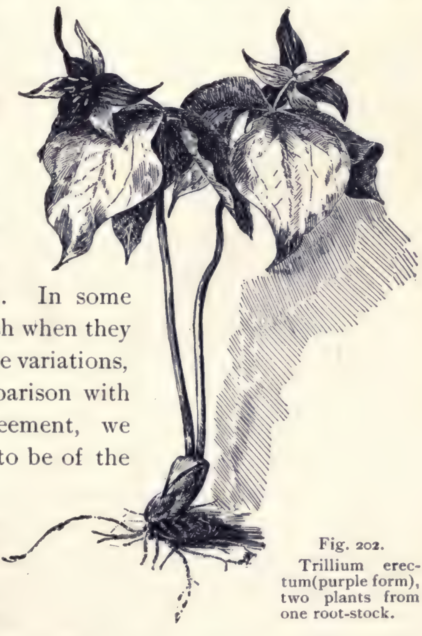


Fig. 202. Trillium erectum(purple form), two plants from one root-stock.

But there are other trilliums which differ greatly from this one. The purple trillium (T. erectum) shown in fig. 202 is very

different from it. So are a number of others. But the purple trillium is a species. It is made up of individuals variable, yet very like one another, more so than any one of them is like the white wake-robin.

375. Genus.—Yet if we study all parts of the plant, the perennial root-stock, the annual shoot, and the parts of the flower, we find a great resemblance. In this respect we find that there are several species which possess the same general characters. In other words, there is a relationship between these different species, a relationship which includes more than the individuals of one kind. It includes several kinds. Obviously, then, this is a relationship with broader limits, and of a higher grade, than that of the individuals of a species. The grade next higher than species we call *genus*. Trillium, then, is a genus. Briefly the characters of the genus trillium are as follows.

376. Genus trillium. — Perianth of six parts: sepals 3, herbaceous, persistent; petals colored. Stamens 6 (in two whorls), anthers opening inward. Ovary 3-loculed, 3–6-angled; stigmas 3, slender, spreading. Herbs with a stout perennial root-stock with fleshy scale-like leaves, from which the low annual shoot arises bearing a terminal flower, and 3 large netted-veined leaves in a whorl.

Note.—In speaking of the genus the present usage is to say trillium, but two words are usually employed in speaking of the species, as Trillium grandiflorum, T. erectum, etc.

377. Genus erythronium. — The yellow adder-tongue, or dog-tooth violet (Erythronium americanum), shown in fig. 203, is quite different from any species of trillium. It differs more from any of the species of trillium than they do from each other. The perianth is of six parts, light yellow, often spotted near the base. Stamens are 6. The ovary is obovate, tapering at the base, 3-valved, seeds rather numerous, and the style is elongated. The flower stem or scape, arises from a scaly bulb deep in the soil, and is sheathed by two elliptical-lanceolate, mottled

leaves. The smaller plants have no flower and but one leaf, while the bulb is nearer the surface. Each year new bulbs are formed at the end of runners from a parent bulb. These runners penetrate each year deeper in the soil. The deeper bulbs bear the flower stems.

378. Genus lilium.—While the lily differs from either the trillium or erythronium, yet we recognize a relationship when we compare the perianth of six colored parts, the 6 stamens, and the 3-sided and long 3-loculed ovary.

Fig. 203.

Adder-tongue (erythronium). At left below pistil, and three stamens opposite three parts of the perianth. Bulb at the right.

379. Family liliaceæ.—The relationship between genera, as between trillium, erythronium, and lilium, brings us to a still higher order of relationship where the limits are broader than in the genus. Genera which are thus related make up the *family*. In the case of these genera the family has been named after the lily, and is the lily family, or *Liliaceæ*.

380. Order, class, group.—In like manner the lily family, the iris family, the amaryllis family, and others which show characters of close relationship are united into an *order* which has broader limits than the family. This order is the lily order,

or order *Liliifloræ.* The various orders unite to make up the *class,* and the classes unite to form a *group.*

381. Variations in usage of the terms class, order, etc. — Thus, according to the system of classification adopted by some, the angiosperms form a *group.* The group angiosperms is then divided into two *classes,* the *monocotyledones* and *dicotyledones.* (It should be remembered that all systematists do not agree in assigning the same grade and limits to the classes, subclasses, etc. For example, some treat of the angiosperms as a class, and as the monocotyledons and dicotyledons as subclasses; while others would divide the monocotyledons and dicotyledons into classes, instead of treating each one as a class or as a subclass. Systematists differ also in usage as to the termination of the ordinal name; for example, some use the word *Liliales* for *Liliifloræ,* in writing of the order.)

382. Monocotyledones.—In the monocotyledons there is a single cotyledon on the embryo; the leaves are parallel veined; the parts of the flower are usually in threes; endosperm is

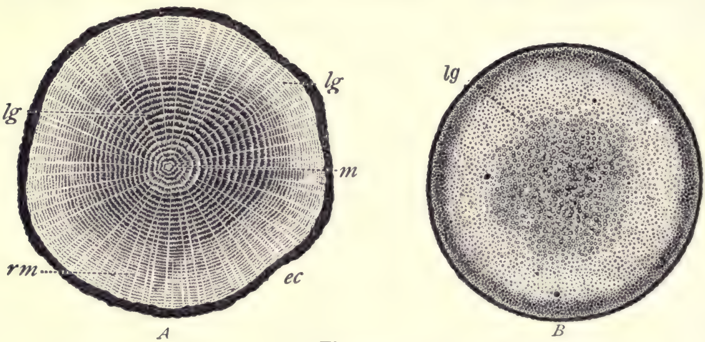


Fig. 204.

A. Cross-section of the stem of an oak tree thirty-seven years old, showing the annual rings. *rm*, the medullary rays; *m*, the pith (medulla). *B.* Cross-section of the stem of a palm tree, showing the scattered bundles.

usually present in the seed; the vascular bundles are usually closed, and are scattered irregularly through the stem as shown by a cross-section of the stem of a palm (fig. 204), or by the arrangement of the bundles in the corn stem (fig. 51). Thus

a single character is not sufficient to show relationship in the class (nor is it in orders, nor in many of the lower grades), but one must use the sum of several important characters.

383. Dicotyledones. — In the dicotyledons there are two cotyledons on the embryo; the venation of the leaves is reticulate; the endosperm is usually absent in the seed; the parts of the flower are frequently in fives; the vascular bundles of the stem are generally open and arranged in rings around the stem as shown in the cross-section of the oak (fig. 204). There are exceptions to all the above characters and the sum of the characters must be considered, just as in the case of the monocotyledons.

384. Taxonomy.—This grouping of plants into species, genera, families, etc., according to characters and relationships is *classification*, or *taxonomy*.

To take Trillium grandiflorum for example, its position in the system, if all the principal subdivisions should be included in the outline, would be indicated as follows:

Group, Angiosperms.
Class, Monocotyledones.
Order, Liliifloræ.
Family, Liliaceæ.
Genus, Trillium.
Species, grandiflorum.

In the same way the position of toothwort would be indicated as follows:

Group, Angiosperms.
Class, Dicotyledones.
Order, Rhœadinæ.
Family, Cruciferæ.
Genus, Dentaria.
Species, diphylla.

But in giving the technical name of the plant only two of these names are used, the genus and species, so that for the toothwort we say *Dentaria diphylla*, and for the white wake-robin, we say *Trillium grandiflorum*.

STUDIES ON PLANT FAMILIES.

CHAPTER XXXVIII.

MONOCOTYLEDONES.

Topic I: Monocotyledones with conspicuous petals (Petaloideæ).

ORDER LILIIFLORÆ.

385. The lily family (liliaceæ). — Trillium grandiflorum which we employed as a representative of the monocotyledons in the morphology of the angiosperms, serves as one type of the lily family. An exercise is added here on the "yellow adder's-tongue" for those who wish to study more than one example of the order. There is an abundance of material from the members of the family if the teacher desires to extend further the exercises on the liliaceæ.

Yellow adder's-tongue (Erythronium americanum). (To be used as an alternate for trillium if preferred.)

Exercise 64.

386. Entire plant.—Observe the bulb from which the flowering scape arises ; the small scale-like leaves overlapping it ; the two large spotted leaves on plants which have the flower. In the case of the nonflowering plants observe that there is only one large leaf. If an opportunity affords for an excursion in the woods where the plant grows, see if you can determine how the bulbs are formed at the ends of the "runners." As to depth in the soil compare the bulbs of the flowering and nonflowering plants.

Inflorescence.—The inflorescence is determinate, and consists of a single terminal nodding flower on a scape.

Flower.—Beginning with the outer whorl of members of the flower determine the number of members in each whorl, as well as their form, relation to each other, and the relation of the different sets among themselves.

Sketch a member of the calyx, corolla, and andrœcium. Sketch the pistil, naming the parts. Make a section of the pistil (preferably one in which the seeds are nearly mature) and determine the number of carpels united to form it. How are the number of carpels manifested in the stigma?

Construct a floral diagram to show the relation and number of the different members of the flower.

The flower of the adder's tongue is *complete*, because it possesses all the floral sets. It is *perfect*, because it possesses both the andrœcium and gynœcium. It is *regular*, because all the members of the calyx, as well as those of the corolla, are of equal size.

387. Other examples of the lily family.—The lily family is a large one. Another example is found in the "Solomon's-seal," with its elongated, perennial root-stock, the scars formed by the falling away of each annual shoot resembling a seal. The onion, smilax, asparagus, lily of the valley, etc., are members of the lily family. The parts of the flower are usually in threes, though there is an exception in the genus *Unifolium*, where the parts are in twos. A remarkable exception occurs sometimes in Trillium grandiflorum, where the flower is abnormal and the parts are in twos.

Outdoor Observations on Some of the Liliaceæ.

If the study of the plant families is carried on during the spring, excursions should be made, if possible, to the fields and woods at opportune times for the purpose of studying some of the plants in their natural surroundings. The short studies given here will serve to indicate some of the observations that can be made during these excursions. For other suggestions, paragraph 455, and the author's larger "Elementary Botany" (Part III, Ecology) should be consulted.

388. Trillium.—As this white flower with its setting of green sepals is glinting to us out of copses and woodland like so many new fairies, few of us realize the long task which it has already begun in the silent depths of the soil in order that it

may suddenly blossom again in season, when springtime returns. If we remove the old scales where the flowering stem joins the root-stock, we see a pointed, conical, white bud, which is to develop into the next season's leafy plant and blossom. From June to August the new leaves and flower are slowly forming, protected by several overlapping, thick, whitish, soft scales, which form a conical roof to keep out water, and to protect against too sudden changes in cold during the autumn and winter season. In September we find that leaves and sepals are well formed and green, the petals are already white, and within are the six stamens and the angular pistil, all well formed. Where the sun reaches these copses and warms the soil well in autumn, sometimes the stamens are yellowish as early as September or October from the already formed pollen. In the cooler shades the pollen is not yet formed and the stamens remain whitish in color. But with the first onset of warm weather in the spring, or on warm days in the winter, before the flower bud lifts its head from its long winter sleep, snugly ensconced among the fallen leaves or spongy humus, the pollen quickly forms. Now all the plant has to do is to erect its standard, bearing aloft the opening blossom.

389. The ovules, begun in the autumn, are now being completed, pollination takes place, and later fertilization, and the embryo begins to form in June. The pure white flowers soon change to pinkish, the first evidence of decline. Finally they wither, and during the summer the fruit and seed are formed on the old flower stem, while the secret formative processes of the new blossoms are going on anew.

390. The adder-tongue (erythronium) comes out early in the spring to catch the sunlight gleaming through rifts in the woodland. It is not so forbidding as its name or its "darting" style would suggest. The rich color of its curved petals nodding from the fork of the variegated leaves lends cheer and brightness to the gray carpet of forest leaves. We are apt to associate the formation of the flower with the early springtime.

Fig. 205.
Trillium grandiflorum. (From photograph by the author.)

But after the flower perishes, the bulb, deep in the soil, slowly builds the next season's flower, which is kept through the autumn and winter, much of the time encased in ice, waiting for springtime that it may rise and unfold.

ORDER GYNANDRÆ.

391. The orchid family (orchidaceæ).—Among the orchids are found the most striking departures from the arrangement of the flower found in the simpler monocotyledons. An example of this is seen in the lady-slipper (cypripedium, shown in fig. 208). The ovary appears to be below the calyx and corolla. This is brought about by the adhesion of the lower part of the calyx to the wall of the ovary. The ovary then is *inferior*, while the calyx and corolla are *epigynous*. The stamens are united with the style by adhesion, two lateral perfect ones and one upper imperfect one. The stamens are thus *gynandrous*. The sepals and petals are each three in number. One of the petals, the "slipper," is large, nearly horizontal, and forms the "lip" or "labellum" of the orchid flower. The labellum is the platform or landing place for the insect in cross-pollination. Above the labellum stands one of the sepals more showy than the others, the "banner." The two lateral "strings" of the slipper are the two other petals. The stamens are still more reduced in some other genera, while in several tropical orchids three normal stamens are present.

Fig. 206.

Flower of an orchid (epipactis), the inferior ovary twisted as in all orchids so as to bring the upper part of the flower below.

There are thus four striking modifications of the orchid

flower: 1st, the flower is irregular (the parts of a set are different in size and shape); 2d, adnation of all parts with the pistil; 3d, reduction and suppression of the stamens; 4th, the ovary is twisted half way around so that the posterior side of the flower becomes anterior. Floral diagrams in fig. 207 show the position of the stamens in two distinct types. The number of orchid species is very large, and the majority are found in tropical countries.

Fig. 207.

Diagrams of orchid flowers. *A*, the usual type; *B*, of cypripedium. (Vines.)

392. Pollination of orchids.—Some of the most marvellous adaptations for cross-pollination by insects are found in the orchids, or members of the orchis family. The larger number of the members of this family grow in the tropics. Many of these in the forests are supported on lofty trees where they are brought near the sunlight, and such are called "epiphytes."

Fig. 208. Cypripedium.

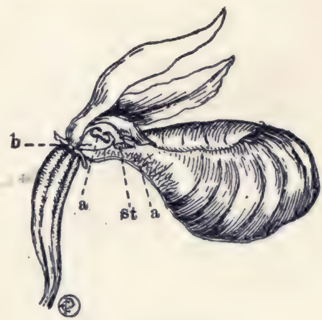


Fig. 209.

Section of flower of cypripedium. *st*, stigma; *a*, at the left stamen. The insect enters the labellum at the centre, passes under and against the stigma, and out through the opening *b*, where it rubs against the pollen. In passing through another flower this pollen is rubbed off on the stigma.

A number of species of orchids are distributed in temperate regions.

393. Cypripedium or lady-slipper.—One species of the lady-slipper is shown in fig. 208. The labellum in this genus is shaped like a shoe, as one can see by the section of the flower in fig. 209. The stigma is situated at *st*, while the anther is situated at *a*, upon the style. The insect enters about the middle of the boat-shaped labellum. In going out it passes up and out at the end near the flower-stalk. In doing this it passes the stigma first and the anther last, rubbing against both. The pollen caught on the head of the insect will not touch the stigma of the same, but will be in a position to come in contact with the stigma of the next flower visited.

Exercise 65.

394. The orchid.—Take one of the orchids, the lady-slipper (cypripedium) for example, and make out the parts of the flower, and the relation of the different members. Study the structure of the flower with reference to the pollination by insects, with the aid of the text, and determine the course which the insect takes to effect cross-pollination.

Material.—Entire plants in flower, including the bulb. This is usually buried deep in the soil, and should be collected fresh if possible. Some of the smaller plants, not in flower, should also be at hand. The plant flowers during May in the northeastern United States. It is represented in other sections by different species. In sections where a species of this genus cannot be obtained another of the orchis family may be employed. (*Apparatus*. Dissecting microscopes, or tripod lenses (the former are better), dissecting needles, scalpel. The apparatus will not be repeated for the following exercises.)

CHAPTER XXXIX.

MONOCOTYLEDONS (CONTINUED).

Topic II: Monocotyledons with flowers on a Spadix (Spadicifloræ).

395. Lesson II. The arum family (araceæ).—This family is well represented by several plants. The skunk's cabbage (Spathyema fœtida), the "jack-in-the-pulpit," also called "Indian-turnip" (Arisæma triphyllum), shown in fig. 210, the water arum (Calla palustris), and the sweet flag (Acorus calamus) are members of this family, as also are the callas and caladiums grown in conservatories. The parts of several of the species of this family, especially the corm of the Indian turnip, are very acrid to the taste. The floral parts are more or less reduced.

396. Relatives of the arum family.—Related to the arum family are the "duckweeds." Among the members of this family are the most diminutive of the flowering plants, as well as the most reduced floral structures.

Other related families are the cat-tails and palms. In the latter the spathe and spadix are of enormous size. The cocoanut is the fruit of the cocoanut palm.

Exercise 66.

INDIAN-TURNIP.

397. Staminate plants (sometimes called male plants).—Sketch an entire plant showing the corm (the thickened perennial stem), the annual shoot with leaves and spathe. Cut away one side of the spathe to expose the long compact cluster of staminate (spadix) flowers within. Sketch the spadix, showing the mass of stamens as well as the sterile part of the shoot above. Dissect off from the axis several of the stamens. Note that the filament is very short, and that the anther is irregularly lobed.

398. The pistillate plants (sometimes called female plants).—Compare with the staminate plant. How many leaves are there? Is the number of leaves constant on all the pistillate plants? Cut away one side of the spathe and expose the spadix of pistillate flowers. Sketch. Observe that each flower consists of a single flask-shaped pistil, and that these are packed closely together. Note the delicate brush-like stigma. Search for plants which show both stamens and pistils on the same spadix. Where both kinds of flowers are present on the same spadix, on what part of the spadix does each kind appear? On the corm of different plants search for lateral buds, which are young plants. Observe that they usually arise on directly opposite sides of the corm; that they easily become freed from the old corms; that they are young corms. Do they arise in the axils of the leaves or scale leaves which have fallen away?

Cut off a portion of the corm. Do not eat any portion but touch the tongue to the cut surface. The flesh of the corm is very acrid.

Description of the Indian-turnip.

399. Indian-turnip.—The "Indian-turnip," or "jack-in-the-pulpit" (Arisæma triphyllum), loves the cool, shady, rich, alluvial soil of low grounds, or along streams, or on moist hillsides. A group of the jacks is shown in figure 210 as they occur in the rich soil on dripping rocks in one of our glens. At their feet is a carpet of moss. Often the violet sits humbly underneath its spreading three-parted leaves. The thin, strap-shaped spathe, unfolded at its base, bends gracefully over the spadix, the sterile end of which stands solitary in the pulpit thus formed. The flowers are very much reduced, i.e., the number of members in the sets is reduced so that they do not appear in threes as in the typical monocotyledons. Some of the members are also often reduced in size or are rudimentary. The plants are "dimorphic" usually.

400. Female plants.—The large plants usually bear the pistillate flowers, which are clustered around the base of the spadix, each flower consisting of a single pistil, oval in form, terminating in a brush-like stigma. The stigma consists of numerous spreading, delicate hairs. The open cavity of the short style is hairy also, and a brush of hairs extends into the cavity of the ovary. Into this brush of internal hairs the necks

of the several ovules crowd their way to the base of the style near its opening. Even when the stigma is not pollinated the

Fig. 210.
A group of jacks.

ovary continues to grow in size, and the stigmatic brush remains fresh for a long time.

401. Male plants.—Excepting some of the intermediate sizes, one can usually select on sight the male and female plants. The smaller ones which have a spathe are nearly all male and bear a single leaf, though a few have two leaves. The male flowers are also clustered at the base of the spadix, and are very much reduced. Each flower consists only of stamens, and singularly the stamens of each flower are joined into one compound stamen, the anther-sacs forming rounded lobes at the end of the short consolidated filaments.

402. The female plants require more food than the male plants.—In some plants both male and female flowers occur on a single spadix, the lower flowers being female, while the upper ones are male. The larger plants are nearly all female, and many, though not all, bear two leaves. In this dimorphism of the plant there is a division of labor apportioned to the destiny and needs of each, and in direct correspondence with the capacity to supply nutriment. The staminate flowers, being short-lived, need comparatively a small amount of nutriment, and after the escape of the pollen (dehiscence of the anthers) the spathe dies, while the leaf remains green to assimilate food for growth of the fleshy short stem (corm), where also is stored nutriment for the growth in the autumn and spring when the leaf is dead. The female plants have more work to do in providing for the growth of the embryo and seed, in addition to the growth of the corm and next season's flower. The smaller female plants thus sometimes exhaust themselves so in seed bearing that the corm becomes small, and the following season the plant is reduced to a male one.

403. Growth and death of the corm.—The new roots each year arise from the upper part of the corm. The stored substances in the base of the corm are used in the early season's growth, and the old tissue sloughs off as the new corm is formed above upon its remains.

Material.—Freshly collected plants should be used, the entire plant; small ones as well as large ones.

CHAPTER XL.

MONOCOTYLEDONS (Concluded).

Topic III: Monocotyledons with a glume subtending the flower (Glumifloræ).

404. Lesson III. Grass family (gramineæ). Oat.—As a representative of the grass family (gramineæ) one may take the oat plant, which is widely cultivated, and also can be grown

Fig. 211.
Spikelet of oat showing two glumes.

Fig. 212.
One glume removed showing fertile flower.

Fig. 213.
Flower opened showing two palets, three stamens, and two lodicules at base of pistil.

Fig. 214.
Section showing ground plan of flower. *a*, axis.

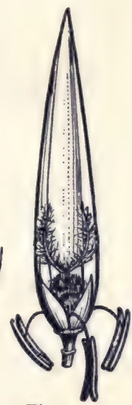


Fig. 215.
Flower of oat, showing the upper palet behind, and the two lodicules in front.

readily in gardens, or perhaps in small quantities in greenhouses in order to have material in a fresh condition for study. Or we

may have recourse to material preserved in alcohol for the dissection of the flower. The plants grow usually in stools; the stem is cylindrical, and marked by distinct nodes as in the corn plant. The leaves possess a sheath and blade. The flowers form a loose head of a type known as a panicle. Each little cluster as shown in fig. 211 is a spikelet, and consists usually here of one or two fertile flowers below and one or two undeveloped flowers above. We see that there are several series of overlapping scales. The two lower ones are "glumes," and because they bear no flower in their axils are empty glumes. Within these empty glumes and a little higher on the axis of the spike is seen a boat-shaped body, formed of a scale, the margins of which are folded around the flowers within, and the edges inrolled in a peculiar manner when mature. From the back of this glume is borne usually an awn. If we carefully remove this scale, the "flower glume," we find that there is another scale on the opposite (inner) side, and much smaller. This is the "palet."

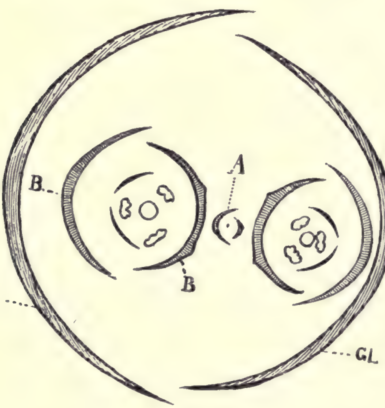


Fig. 216.
Diagram of oak spikelet. *Gl*, glumes; *B*, palets; *A*, abortive flower.

Next above this we have the flower, and the most prominent part of the flower, as we see, is the short pistil with the two plume-like styles, and the three stamens at fig. 213. But if we are careful in the dissection of the parts we shall see, on looking close below the pistil on the side of the flowering glume, that there are two minute scales (fig. 215). These are what are termed the *lodicules*, considered by some to be merely bracts, by others to represent a perianth, that is two of the

sepals, the third sepal having entirely aborted. Rudiments of this third sepal are present in some of the gramineæ.

405. Other members of the grass family.—To the gramineæ belong also the wheat, barley, corn, the grasses, rice, etc. It is one of the most important families from an economic standpoint, furnishing a great variety of food for man and other animals. The gramineæ, while belonging to the class monocotyledons, are less closely allied to the other families of the class than these families are to each other. For this reason they are regarded as a very natural group.

Exercise 67.

406. The wheat (Triticum sativum vulgare).—The wheat plant may be studied as an alternate for the oat plant.

The entire wheat plant.—Study the entire wheat plant, and compare with the oat plant. Are the stems of the wheat single or are stools formed? Since a germinating grain of wheat forms at first but a single stem, how are the stools formed? Examine young wheat plants to determine this.

The inflorescence.—The "head" of wheat forms a single spike. Sketch a spike. Remove a few of the spikelets, and note the jointed and zigzag character of the axis (rachis) of the spike; note the attachment of the spikelets.

The spikelets.—Note the empty glumes at the base; determine how many flowers there are in a spikelet. How many flowering glumes and palets are there to each flower? In a mature head of wheat determine how many of the flowers in a spikelet ripen grain, and how many are sterile? Are there any of the spikelets which are completely sterile? Where are they located?

Using a head of wheat at the time of flowering, spread apart the members of a flower with the aid of dissecting needles, and sketch the parts of the flower, showing the glume, palet, the three stamens, and the pistil with the plumose styles. Endeavor to find the lodicules. (See the description of the oat flower for comparison.)

Sketch an empty and a flowering glume to show the "nerves" and awns. Compare the grain of wheat with a grain of corn. (See paragraph 9.)

Material.—Entire stools of young, fresh plants (may be obtained at any time during autumn, winter, or spring); mature plants in flower (if they cannot be obtained fresh they may be dried, preserving at the same time some of the flowering heads in alcohol or formalin); ripe heads of wheat.

CHAPTER XLI.

DICOTYLEDONS.

Topic IV: Dicotyledons with distinct petals, flowers in catkins, or aments; often degenerate.

ORDER AMENTIFERÆ.

407. Lesson IV. The willow family (salicaceæ).—The willows represent a very interesting group of plants in which the

Fig. 217.
Spray of willow leaves, pistillate and staminate catkins (Salix discolor).

flowers are greatly reduced. The flowers are crowded on a more or less elongated axis forming a *catkin*, or *ament*. The

ament is characteristic of several other families also. The willows are diœcious, the male and female catkins being borne on different plants. The catkins appear like great masses of either stamens or pistils. But if we dissect off several of the flowers from the axis, we find that there are many flowers, each one subtended by a small bract. In the male or "sterile" catkins the flower consists of two to eight stamens, while in the female or "fertile" catkins the flower consists of a single pistil. The poplars and willows make up the willow family.

Exercise 68.

408. The willow (Salix discolor).

The leafy shoot.—Determine the arrangement of the leaves of the willow; sketch a leaf showing its form, the character of the margin, and of the venation. If different willows are at hand compare the color of the twigs, as well as the character of the twigs as to brittleness or litheness.

The inflorescence.—What is the kind of inflorescence? Are both kinds of flowers borne on the same ament (catkin), or on different aments?

The staminate catkins.—Determine what constitutes a flower by dissecting some of them off from the axis of the catkin. What parts of the flower are present? How many stamens in a flower? If a hand lens is convenient use it in making out the form of the parts. Sketch a flower in its position on the axis of the catkin, showing also the bract at the base of the flower. Describe the character of the bract as seen under the lens.

The pistillate catkin.—What parts of the flower are present? Compare with the staminate flower. Sketch a pistillate flower with the subtending bract to show the form of the ovary, with the divided stigma. Is the pistil sessile or stalked? How many carpels make up the pistil? Is there a small gland (nectary) present near the base of the ovary which represents the perianth? Is there a nectary on the staminate flower?

The fruit.—Examine ripe pods of the willow. Determine what parts of the flower unite to form the fruit. What difference between a fruit and seed in the willow? What means is provided for the dissemination of the seeds?

Field observations on the willows.—At what time do the catkins of the willow appear? Do they flower before the leaves appear? At time of flowering note the character and abundance of the pollen from the stamens. Is it in the form of "dust," or is it adhesive? How are the willows pollinated? Do insects visit the willow flower? Are willows easily propagated by shoots? What happens if a willow branch is stuck into damp soils; when it is left in the water for some time?

Material.—Shoots of the willow, some with leaves, some with the catkins (the two kinds of catkins occur on different plants). If material cannot be obtained fresh when wanted for study, the leafy shoots may be preserved dry, and the catkins in alcohol or formalin, or dry. Ripe fruit should also be at hand; this may be preserved dry.

ORDER AMENTIFERÆ.

409. Lesson V. The oak family (cupuliferæ).—A small branch of the red oak (Quercus rubra) is illustrated in fig. 218.

Fig. 218.

Spray of oak leaves and flowers. Below at right is staminate flower, at left pistillate flower.

This is one of the rarer oaks, and is difficult for the beginner to distinguish from the scarlet oak. The white oak is perhaps

in some localities a more convenient species to study. But for the general description here the red oak will serve the purpose. Just as the leaves are expanding in the spring, the delicate sprays of pendulous male catkins form beautiful objects. The petals are wanting in the flower, and the sepals form a united calyx, with several lobes, that is, the parts of the calyx are *coherent.* In the male flowers the calyx is bell-shaped and deeply lobed. The pendent stamens, variable in number, just reach below its margin. The pistillate or female flowers are not borne in catkins, but stand on short stalks, either singly or a few in a cluster. The calyx here is urn-shaped with short lobes. The ovary consists of three united (coherent) carpels, and there are three stigmas. Only one seed is developed in the ovary, and the fruit is an acorn. The numerous scales at the base of the ovary form a scaly involucre, the *cup.*

The beech, chestnut, and oak are members of the oak family.

410. Other ament bearers.—The following additional families among the ament bearers are represented in this country: the birch family (birch, alder), the hazelnut family (hazelnut, hornbeam, etc.), walnut family (hickory, walnut), and the sweet-gale family (myrica).

Exercise 69.

411. The oak.—(The white oak or any common one in the neighborhood.)

The leaves.—Determine the arrangement of the leaves on the shoot. Sketch a leaf showing the form, outline, and venation. Compare the young leaves with the old ones as to texture, surface characters, etc.

The inflorescence.—What is the kind of inflorescence? Are both kinds of flowers in the same inflorescence or in different inflorescences?

The staminate inflorescence.—Note the cluster of staminate aments. Determine a single flower and sketch it to show the parts. What parts of the flower are present? Determine the number of parts of each set present.

The pistillate inflorescence.—How does it differ from the staminate inflorescence? Sketch a pistillate flower, showing the parts. What parts of the flower are present?

The fruit (an acorn with the cup).—Sketch an acorn in the "cup."

What is the homology of the cup? i.e., to what part or series of members of the plant does it belong? Could the pistillate flower of the ancestors of the oak have been in the form of aments, and if so could the cup of the acorn represent the degraded and consolidated ament? If so, what part of the ament would now be represented in the cup? (It has also been suggested that the scales of the involucre which make up the cup are adventitious growths accompanying the development of the fruit.)

(If the acorn has not been studied under the paragraph dealing with seeds and fruits, and if there is time now, remove the wall of the acorn and determine the parts of the embryo. Are any parts of the embryo green while still enclosed within the acorn?

Field observations on the oaks.—Compare the time of appearance of the flowers and leaves of the oak. What about the abundance of the pollen? How are the oaks pollinated? The ament-bearing plants are usually wind pollinated, and for this reason there is an abundance of pollen, and always in the form of dust. Is there an exception to this general rule? How long after the flowers are formed before the acorn is ripe?

If there is time during excursions note other ament-bearing plants.

Material.—Mature leaves, leafy shoots, sprays of the flowers, both pistillate and staminate; fruit (the acorn in the cups).

CHAPTER XLII.

DICOTYLEDONS (CONTINUED).

Topic V: Dicotyledons with distinct petals and hypogynous flowers.

ORDER URTICIFLORÆ.

412. Lesson VI. The elm family (ulmaceæ).—The elm tree belongs to this family. The leaves of our American elm (Ulmus americana) are ovate, pointed, deeply serrate, and with an oblique base as shown in fig. 219. The narrow stipules

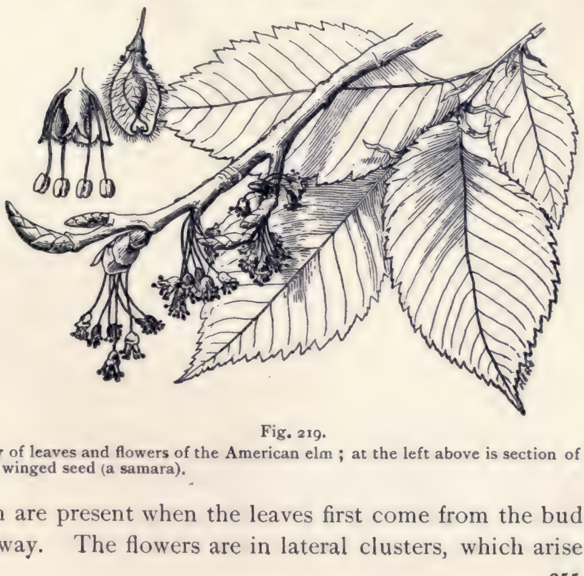


Fig. 219.

Spray of leaves and flowers of the American elm; at the left above is section of flower, next is winged seed (a samara).

which are present when the leaves first come from the bud soon fall away. The flowers are in lateral clusters, which arise from

the axils of the leaves, and appear in the spring before the leaves. They hang by long pedicels, and the petals are absent. The calyx is bell-shaped, and 4–9-cleft on the margin. The stamens vary also in number in about the same proportion. A section of the flower in fig. 219 shows the arrangement of the parts, the ovary in the centre. The ovary has either one or two locules, and two styles. The mature fruit has one locule, and is margined with two winged expansions as shown in the figure. This kind of a seed is a *samara.*

Exercise 70.

413. The elm (Ulmus americana).

Leaves.—What is the arrangement of the leaves on the shoot? Sketch a leaf showing its attachment to the shoot, and the relation of the stipules; note how easily the stipules fall away.

The inflorescence.—Describe the inflorescence; a single flower; sketch a single flower in the position in which it stands on the tree. Cut away the floral envelope on one side; determine the number of stamens; the number of pistils; are the pistils single or compound? Of how many carpels is it composed? Sketch a flower with the front part of the envelope and the front stamens removed. What part of the floral envelope is present? What is its character and form? What are the relations of the sets of the flower to each other? In time of appearance how do the flowers compare with the leaves?

Describe the mature fruit; how many seed are present? What parts of the flower are united in the fruit? What is the fruit called?

Materials.—Spray of leaves and flowers; it may be necessary to collect them at different times. Leafy shoots should be collected while some of the leaves are still young in order to preserve some with the stipules, and they may be preserved dry and pressed. Fruits collected at the time of maturity may be preserved dry.

ORDER POLYCARPICÆ.

414. Lesson VII. The crowfoot family (ranunculaceæ).—The marsh-marigold (Caltha palustris) is a member of this family. The leaves are heart-shaped or kidney-shaped, and the edge is crenate. The bright golden-yellow flowers have a single whorl of petal-like envelopes, and according to custom in such cases they are called sepals. The number is not

definite, varying from five to nine usually. The stamens are more numerous, as is the general rule in the members of the family, but the number of the pistils is small. Each one is separate, and forms a little pod when the seed is ripe. The marsh-marigold, as its name implies, occurs in marshy or wet places and along the muddy banks of streams. It is one of the common flowers in April and May.

Fig. 220.
Caltha palustris, marsh-marigold.

Exercise 71.

415. The Buttercup.—If preferred, a species of buttercup may be studied instead of the marsh-marigold, but a comparison with the latter is desirable.

The entire plant.—Describe form and habit of the plant; the character of the stem; branching; the form and arrangement of the leaves; the character of the roots (these characters will depend on the species).

The inflorescence.—What kind of inflorescence? What parts of the flower are present? Describe the color and form of members of the different sets of the flower. Determine the number of members in each set (approximately if not accurately).

Fig. 221.
Diagram of marsh-marigold flower.

Sketch a sepal, a petal (is a nectar gland present?), a stamen, and a pistil, noting carefully the characters of each.

Do the stamens all ripen their pollen at the same time? Is there any advantage as regards the time of ripening of the stamens?

What is the relation of the members of a set among themselves? What is the relation of the sets to each other?

Is the flower perfect or imperfect; complete or incomplete? Is it regular or irregular; hypogynous, perigynous, or epigynous? Are the parts of the flower free and distinct, or adherent, or coherent?

If fruit is present determine the number of seed in a ripe fruit; and also what parts of the flower make up the fruit.

If there is time a comparison of the flowers, fruit, and leaves of different species of the ranunculus will be found interesting, especially species from dry and wet ground as well as some of the species which grow in the water.

Construct the formula for the buttercup flower; also construct the floral diagram.

Material.—Entire plants, some flowering stems with flowers, some with fruit. Fresh material when possible.

THE BUTTERCUP (RANUNCULUS).

416. Other crowfoots.—Many of the crowfoots or buttercups (ranunculus) with bright yellow flowers grow in similar situations. The "wood anemone" (anemone), small plants with white flowers, and the rue anemone (anemonella), which resembles it, both flower in woods in early spring. The common virgin's bower (Clematis virginiana) occurs along streams or on hillsides, climbing over shrubs or fences. The vine is somewhat woody. The leaves are opposite, petioled, and are composed of three leaflets, which are ovate, three-lobed, and usually strongly toothed, and somewhat heart-shaped at the base. The flower clusters are borne in the axils of the leaves, and therefore may also be opposite. The clusters are much branched, forming a convex mass of beautiful whitish flowers. The sepals are colored and the petals may be absent, or are very small. The stamens are numerous, as in the members of the crowfoot family. The pistils are also numerous, and the achenes in fruit are tipped with the long plumose style, which aids them in floating in the air.

417. Character of the ranunculaceæ.—Some of the characters of the ranunculaceæ we recognize to be the following: The plants are mostly herbs, the petals are separate, and when the corolla is absent the sepals are colored like a corolla. The stamens are numerous, and the pistils are either numerous or few, but they are always separate from each other, that is they are not fused into a single pistil (though sometimes there is but

one pistil). All the parts of the flower are separate from each other, and make up successive whorls, the pistils terminating the series. When the seeds are ripe the fruit is formed, and may be in the form of a pod, or achene, or in the form of a berry, as in the baneberry (actæa).

ORDER RHŒADINÆ.

418. Lesson VIII. The mustard family (cruciferæ).—This is well represented by the toothwort (dentaria), which we studied in a former chapter. (If the toothwort has been studied, the shepherd's-purse may be omitted.)

Exercise 72.

419. The Shepherd's purse (Capsella bŭrsa-pastoris).—If it is desired to study a species besides the toothwort the shepherd's-purse will answer. It is a common and widely distributed species, found in waste places and in fields.

The entire plant.—Note and describe the habit and character of the plant, i.e., the size, character of branching, character of the root, position and arrangement of the leaves. Compare the "radicle" (lower) leaves with the "cauline" (stem) leaves as to form, and insertion. The radicle leaves are more or less deeply lobed or pinnatifid (pinnately cut), while the stem leaves are slender, lanceolate, toothed, and often auricled (with little ears) at the base.

The inflorescence.—What is the kind of inflorescence? Determine the parts of the flower present, as well as the number and arrangement of the members of the flower. What figure do the petals make in the flower, which suggests the name of the family to which the shepherd's purse and the toothwort belong?

The fruit.—What parts of the flower are united in the fruit? Compare the plant with the toothwort.

Construct the floral diagram of the toothwort or shepherd's purse, or of other cruciferous plant studied.

Material.—Entire plants with flowers and fruit. The plant occurs from early spring to autumn, and can be usually obtained in a fresh condition when wanted.

The exercise on the violet may be omitted unless it is desired to study it in connection with some field observations, and for the purpose of observing "cleistogamous" flowers, when the outline here given will answer.

ORDER CISTIFLORÆ.

420. The violet family (violaceæ).—The violet family is represented by the common blue violet, the yellow violet, the pansies, heart's ease, sweet violet, etc.

Exercise 73.

421. The blue violet (Viola cucullata).

The entire plant.—Describe the character and habit of the plant, the short underground stem, the "radicle" leaves, the erect flower scapes which bear the conspicuous blue flowers, and the short, curved stems beneath the soil or débris which bear the closed inconspicuous flowers. Sketch a leaf, showing the form and venation. What is the form of the leaf and the character of the margin?

The blue flowers.—Sketch a flower. Is the flower regular or irregular? complete or incomplete? perfect or imperfect?

The calyx.—Describe the form of the calyx; how many sepals are indicated?

The corolla.—How many petals are present? Remove them and note carefully the form of each one and the position in the flower. In the "spurred" one look for nectar glands.

The stamens.—Determine the number of the stamens. Are they united together by their anthers? If so the stamens are said to be *syngenecious*. Are the stamens of different sizes? Describe the form of the different ones and the relation of certain peculiar ones to the spur of the corolla.

The pistil.—Describe the form of the pistil and the relation of the stamens and pistils.

The closed (cleistogamous) flowers.—These are on shorter, curved, scapes which hold them beneath the soil or débris. Compare them with the blue flowers. What parts of the flower are absent?

The fruit.—Make a cross-section of the fruit and determine how many carpels are represented in the pistil. Note the numerous seeds.

Pollination of violets.—If a sweet violet flower, or the flowers of the pansy are convenient, study the stamens and pistil of the open flowers. Remove the corolla, and note the position of the anthers with reference to the pistil. Note the peculiar enlarged stigma with an opening in front, and the lip below. Move a pencil into a flower, endeavoring to imitate the entrance of an insec and try to determine how cross-pollination takes place. Compare the blue flowers of the blue violet.

The small closed flowers are called cleistogamous, and they are *self-polli-*

nated, because being closed, and because of the position of the anthers around the stigma the pollen from the opening anthers comes directly in contact with the stigma. In the flowers of the pansy cross-pollination often takes place

Fig. 222.

Viola cucullata ; blue flowers above, cleistogamous flowers smaller and curved below. Section of pistil at right.

through the agency of insects. While the blue flowers of the blue violet rarely set fruit, nevertheless pollination and fertilization do take place in some of the flowers, though fruit sets more abundantly in the cleistogamous flowers.

Material.—Entire plants with the flowers ; collect some early in the season when the blue flowers are abundant, and some later when the small flowers underneath the soil or leaves are formed. Mature fruit is also desirable.

CHAPTER XLIII.

DICOTYLEDONS (CONTINUED).

Topic VI: Dicotyledons with distinct petals and perigynous or epigynous flowers. Many trees and shrubs.

ORDER ÆSCULINÆ.

422. Lesson X. The maple family (aceraceæ).—Figure 223 represents a spray of the leaves and flowers of the sugar maple

Fig. 223.
Spray of leaves and flowers of the sugar maple.

(Acer saccharinum), a large and handsome tree. The leaves are opposite, somewhat ovate and heart-shaped, with three to

five lobes, which are again notched. The clusters of flowers are pendulous on long hairy pedicels. The petals are wanting. The calyx is bell-shaped and several times lobed, usually five times. The stamens are variable in number. The ovary is two-lobed and the style deeply forked. The fruit forms two seeds, each with a long wing-like expansion as shown in the figure. The flowers of the maple are polygamo-diœcious, that is the male members (stamens) and female members (carpels) may be in the same flower or in different flowers.

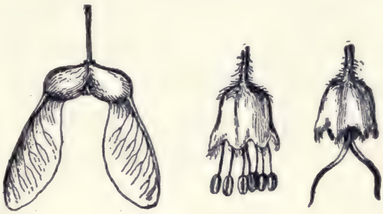


Fig. 224.

Seeds and flowers of sugar maple. At the right is a pistillate flower, in the middle a staminate flower, and at the left the two seeds forming a samara.

Exercise 74.

423. The sugar maple (Acer saccharinum).—(Another species may be studied if desired.)

Leaves.—Determine the form and arrangement of the leaves; sketch a leaf.

Inflorescence.—Describe the character of the inflorescence; sketch a flower cluster.

Flowers.—Select several different flowers, some from different trees, and compare them carefully to see if the members of the flower are the same in all. Sketch several to show the general character.

What parts of the flower are present? Describe the form and character of each set of members, and their relation to each other. Determine the number of members in each set and their relations among themselves. Study several flowers to make this out.

The fruit.—Sketch a fruit. What parts of the flower are united in the fruit?

If there is time it will be found instructive to compare the flowers of another species of maple, like the red maple, with the sugar maple. Examine different flowers from several different trees in order to compare the different sizes of the stamens and pistils in different flowers, and the facts with reference to the presence or absence of any of the members in certain of the flowers. Compare the leaves of the red maple with those of the sugar maple also.

Materials.—Leafy shoots, either fresh or pressed and dried. Flowers; fresh as they appear in the spring; if they cannot be studied immediately they may be preserved in alcohol or in formalin. They are better fresh.

Fruits, collected in the autumn and preserved dry.

Omit the study of the horse chestnut, unless it is desired to study it instead of the maple, since it belongs to the same order.

424. The buckeye family (hippocastanaceæ).—The horse chestnut (Æsculus hippocastanum) is largely planted in the Northeastern United States as an ornamental tree. It is also self-seeding in waste places. The family is represented in other places by other species, the buckeye, from which the family gets its common name, for example occurs in Ohio (the Buckeye State).

Exercise 75.

425. The horse chestnut (Æsculus hippocastanum).

The leaves.—Note the form and arrangement of the leaves. Sketch a leaf to show its form and the parts. What kind of a leaf is it?

The inflorescence (mixed racemose).—The flowers. What parts of the flower are present? Is the flower complete or incomplete; regular or irregular; perfect or imperfect?

Describe the calyx; the corolla; describe a petal, its form and color. How many petals present?

The stamen.—How many present? Sketch a stamen.

The pistil.—Describe the form of the pistil, its parts; how many carpels are represented in the pistil? What is the character of the surface of the ovary?

The mature fruit.—What is the character of the surface of the mature fruit? Describe the form of the fruit. What parts of the flower are united to form the fruit? What is the difference between the fruit and a seed in the horse chestnut? Examine the embryo in the seed; note its large cotyledons and the well developed hypocotyl. Why is the embryo not good for food for man?

Construct the floral diagram of the horse-chestnut flower.

Material.—Sprays of leaves and flowers, collected fresh. Mature fruits.

CHAPTER XLIV.

DICOTYLEDONS (CONTINUED).

ORDER ROSIFLORÆ.

426. Lesson XI.—The rose-like flowers are an interesting and important group. In all the members the receptacle (the end of the stem which bears the parts of the flower) is an important part of the flower. It is most often widened, and either cup-shaped or urn-shaped, or the centre is elevated. The carpels are borne in the centre in the depression, or on the elevated central part where the receptacle takes on this form. The calyx, corolla, and the stamens are usually borne on the margin of the widened receptacle, and where this is on the margin of a cup-shaped or urn-shaped receptacle they are said to be *perigynous*, that is, around the gynœcium. The calyx and corolla are usually in fives. There are three families, as follows.

Fig. 225.
Perigynous flower of spiræa (S. lanceolata). (From Warming.)

427. The rose family (rosaceæ).—In this family there are five types, represented by the following plants and illustrations: 1st. In spiræa (fig. 225) the receptacle is cup-shaped. There are five carpels, united at the base, but free at the ends. 2d. In the strawberry the receptacle is conic and bears the carpels (fig. 226). The conic receptacle becomes the fleshy fruit, with the seeds in little pits

over the surface. 3d. The raspberries, blackberries, etc., represented here by the flowering raspberry (Rubus odoratus), fig. 227. 4th. This is represented by the roses. The receptacle is urn-shaped and constricted toward the upper portion, with the carpels enclosed in the base (fig. 228). 5th. Here the receptacle is cup-shaped or bell-shaped and nearly closed at the mouth as in the agrimony.

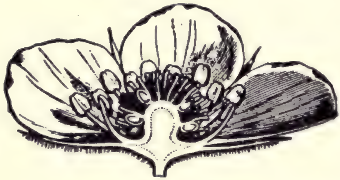


Fig. 226.
Flower of Fragaria vesca with columnar receptacle. (From Warming.)

428. Lesson XII. The almond or plum family (amygdalaceæ).—The members of this family are trees or shrubs. The common choke-cherry (fig. 229) will serve to represent one of the types. The flowers of this species are borne in racemes. The receptacle is cup-shaped. Only one seed in the single carpel (sometimes two carpels) matures as the calyx falls away.

Fig. 227.
Flowering raspberry (Rubus odoratus).

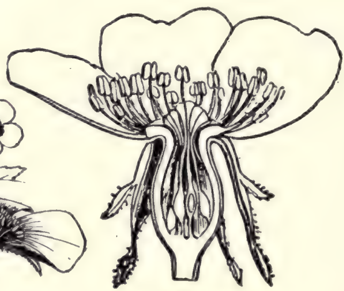


Fig. 228.
Perigynous flower of rosa, with contracted receptacle. (From Warming.)

The outer portions of the ovary become the fleshy fruit, while the inner portion becomes the hard stone with the seed in the centre. Such a fruit is a *drupe*.

The floral formula for this family is as follows:

$$Ca5, Co5, A15\text{–}20 \text{ or } 30, G1.$$

429. Lesson XIII. The apple family (pomaceæ).—This family is represented by the apples, pears, quinces, june-berries,

Fig. 229.
Choke-cherry (Prunus virginiana). Leaves, flower raceme, and section of flower at right.

hawthorns, etc. The members are trees or shrubs. The receptacle is somewhat cup-shaped and hollow. The perianth and stamens are at first perigynous, but become epigynous

(upon the gynœcium) by the fusion of the receptacle with the carpels. The floral formula is thus Ca5,Co5,A10–5–5 or

Fig. 230.
Flower of pear. (After Warming.)

10–10–5,G1–5. The carpels are united, but the styles are free. In fruit the united carpels fuse more or less with the receptacle.

Omit either the strawberry, or the apple, as an exercise, if desired.

Exercise 76.

430. The strawberry (Fragaria vesca).

Describe the appearance of the entire plant. What different stems are there? What purpose does each kind of stem serve? Sketch and describe a leaf.

The inflorescence.—What is the kind of inflorescence?

The flower.—Determine the parts of the flower present. Describe each set of members of the flower, naming the kind of calyx and corolla. Are the sets of members free? Are the members of each set distinct? To take the flower as a whole in its young condition (just opening) what is the relation as regards position and elevation of the different sets to each other? Is the flower perigynous or hypogynous?

What is the end of the stem called to which the parts of the flower are attached?

Do all the flowers of the strawberry form fruit? When you have determined this, determine the reason if you can.

The fruit.—What parts of the flower are united to form the fruit? What is such a fruit called? What part of the flower forms the fleshy part of the fruit? What parts of the flower are united in the seed? What is such a seed called?

How does seed distribution come about in such plants as the strawberry? How are strawberry plants usually propagated?

Materials.—Entire plants with runners: flowers; fruit.

Exercise 77.

431. The apple (Pyrus malus).

Leaves.—Determine the arrangement of the leaves on the shoot; sketch a leaf.

The inflorescence.—Determine the kind of inflorescence.

The flower.—Study several flowers to compare the variation in the number of the parts or members of the flower. What parts of the flower are present?

Make a long section of the flower and sketch showing the parts and their relation to each other.

Determine the number of members in each set; the relation of the members of a set to each other; the relation of the sets among themselves. Give the names which are applied to these relations.

The fruit.—What parts of the flower are united in the fruit? Make longitudinal and cross-sections of an apple, name the parts and show from which part of the flower each part of the fruit comes. What is the fruit of an apple-tree called?

Materials.—Spray of leaves and flowers; mature fruit.

Order Leguminosæ.

432. Lesson XIV. The pea family (papilionaceæ).—This family is well represented by the common pea. The flower is butterfly-like or *papilionaceous*, and the showy part is made up

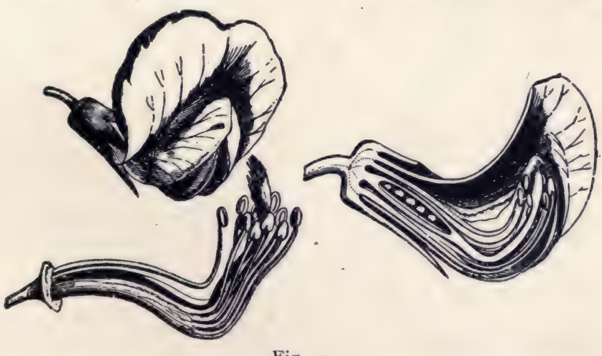


Fig. 231.

Details of pea flower; section of flower, perianth removed to show the diadelphous tamens, one single one, and nine in the other group. (From Warming.)

of the five petals. The petals have received distinct names here because of the position and form in the flower. At fig. 232 the petals are separated and shown in their corresponding positions, and the names are there given. The flower is irregular and the parts are in fives, except the carpel, which is single. The calyx is gamosepalous (coherent), the corolla polypetalous (distinct). The ten stamens are in two groups, one separate stamen and nine united; they are thus diadelphous (two brotherhoods). The fruit forms a pod or legume, and at maturity splits along both edges.

Fig. 232.
Corolla of pea. *S*, standard; *W*, wings; *K*, two petals forming keel.

There are three families in the legume-bearing plants: 1st, including the locusts, cassias, etc.; 2d, the pea family, including peas, beans, clovers, ground-nuts, or peanuts, vetches, desmodium, etc.; 3d, including the sensitive plants like mimosa.

Exercise 78.

433. The pea (Pisum sativum).

The entire plant.—Describe the entire plant, the branching, the means for support (compare different cultivated varieties in respect to size, habit, and means for support if practicable).

The leaf.—Sketch a leaf; name the different parts; what kind of a leaf is it? Does the leaf serve any purpose for the mechanical support of the plant? How?

The inflorescence.—What is the kind of inflorescence?

The flower.—Is it regular or irregular?

The calyx.—Describe the calyx. How many sepals are indicated? Are the sepals distinct or coherent? What name is applied to this kind of a calyx?

The corolla.—What are the relations of the petals to each other? What term is applied to indicate this relation? Sketch a flower, and name the different parts of the corolla; what name is given to such a flower?

The stamens (remove the corolla); how many stamens are there? What is their relation to each other? What terms are used to indicate such a relation of stamens to each other?

The pistil.—How many carpels in the pistil? Is it simple or compound? Sketch a young pistil, naming the parts.

The fruit.—What parts of the flower are united in the fruit? Describe the fruit. What is such a fruit called? How are the seeds freed? What is the difference between a fruit and a seed in the pea plant?

The clover (trifolium).—If it is desired to study a clover, study one in a similar way.

Nitrogen gatherers. — The pea, clovers, etc., are often called nitrogen gatherers (see Chapter XV). During an excursion let the pupils dig up different leguminous plants, like the pea, clover, lupine, etc., and search for the "tubercles" on their roots, comparing the form of the tubercles on the different kinds of plants.

Pollination.—If the flowers of cytisus from a conservatory are at hand attempt to press the point of a pencil in between the parts of the keel in the case of flowers where these parts are still closed; describe the action of the stamens in throwing the pollen. How could cross-pollination be brought about in such a flower by the visits of insects?

Study the common lupine (Lupinus perennis) in the same way. Study the pea flower with the same object in view; has the pea flower become adapted to self-pollination?

Material.—Sprays of leaves and flowers; fruit. Material can usually be obtained fresh early in the spring and for some time later.

Fig. 233.
Section of flower of Œnothera.

Topic VII: Dicotyledons with distinct petals and epigynous flowers.

ORDER MYRTIFLORÆ.

(The study of the evening primrose may be omitted.)

434. Lesson XV. The evening-primrose family (onograceæ).—In the evening-primrose (œnothera) the flowers are arranged

Fig. 234.
Evening primrose (Œnothera biennis) showing flower buds, flowers, and seed pods. (From Kerner and Oliver.)

in a loose spike along the end of the stem, each one situated in the axil of a leaf-like bract. The flowers of the family are very characteristic, as shown here. They are sessile in the axil of the bract, and the calyx forms a long tube by the union of the sepals, only the end of the tube being divided into the individual parts, showing four lobes. On the edge of the open end of the calyx tube are seated the four, somewhat heart-shaped, yellowish petals, and here are also seated the eight stamens. The four carpels are united into a single pistil within the base of the calyx tube and united with it, so that the calyx tube seems to be on the end of the pistil. The flowers soon fade and fall away from the pistil, and this grows into an elongated four-angled pod. Since the lower flowers on the stem are the older, we find nearly mature fruit and fresh flowers, with all intermediate grades, on the same plant.

The plants grow by roadsides and in old fields. They are from 10*cm* to a meter or more high (one to five feet). The leaves are lanceolate or oblong, toothed and repand on the margin. In many of the species of the family the parts of the flower are in fours as in the evening primrose, but in others the number is variable.

CHAPTER XLV.

DICOTYLEDONS (CONTINUED).

SYMPETALÆ.

435. In the remaining families the corolla is *gamopetalous*, that is, the petals are coherent into a more or less well-formed tube, though they may be free at the end. For this reason they are known as the *sympetalæ*.

Topic VIII: Dicotyledons with united petals, flower parts in five whorls.

ORDER BICORNES.

436. Lesson XVI. The whortleberry family (vacciniaceæ).—(This study may be omitted.)—The common whortleberry, or huckleberry (Gaylussacia resinosa), flowers in May and June. The shrubs are from 30*cm* to 1 meter (1–3 feet) high, and are much branched. The leaves are ovate, and when young are more or less clammy from numerous resinous dots, from which the plant gets its specific name (resinosa). The flowers are borne on separate shoots from the leaves of the same season, and hang in one-sided short racemes as shown in fig. 235. The calyx is short, five-lobed, and adheres to the ovary. The corolla is tubular, at length cylindrical with five short lobes, and is whitish in color. The stamens are ten in number, and the compound ovary has a single style. The fruit is a rounded black, edible berry or drupe, with ten seeds.

Topic IX: Dicotyledons with united petals, flower parts in four whorls.

ORDER TUBIFLORÆ.

437. Lesson XVII. The mint family (labiatæ).—The mint family contains a large number of genera and takes its common name from the mints, of which there are several species belonging to the genus mentha. In the figure of the "dead-nettle"

Fig. 235.
Whortleberry (Gaylussacia resinosa).

Fig. 236.
Spray of dead-nettle (Laminum amplexicaule), leaves and flowers.

(Lamium amplexicaule), which is also one of the members of this family, we see that the lobes of the irregular corolla are arranged in such a manner as to suggest two lips, an upper and a lower one. From this character of the corolla, which obtains in nearly all the members, the family receives its name of *Labiatæ*. The calyx is five-lobed. The stamens, four in number, arise from the tube of the corolla, and converge in

pairs. The ovary is divided into four lobes, and at the maturity of the seed these form four nutlets. The leaves are rounded, crenate on the margins, the lower ones petioled and heart-shaped, and the upper ones sessile and clasping around the stem beneath the flower clusters. From the clasping character of the upper leaves the plant derives its specific name of *amplexicaule*. The plant occurs in waste places and is rather common.

Fig. 237. Diagram of lamium flower.

Of the two exercises given below one may be omitted.

Exercise 79.

438. The catnip (Nepeta cataria).—While the "dead nettle" is used here to illustrate the mint family other species may be studied instead. The exercise is written for the catnip (Nepeta cataria), a very common weed occurring from July to September. If fresh material is not at hand when the study is made, dried entire plants, and the flowers in formalin may be used, unless it is preferred to use fresh material of some other available species. In that case the dead nettle here illustrated, and the exercise, will serve as a guide for the study.

The entire plant.—Note the habit, the character of the branching, the shape of the stem, the character of the surface. Note the form and arrange- of the leaves. Is the plant annual, biennial, or perennial?

The inflorescence.—What is the inflorescence? **The flower**; the parts present, **the calyx,** form and relation of parts; **the corolla**; form, relation of parts; into what two parts is the corolla divided? the name of the two parts? the number of petals in each part? Note the **stamens,** number, size, position in the flower. **The pistil**; sketch a pistil showing the nutlets, the long style.

To study the stamens remove a corolla, split it open down one side and spread it out on a glass slip and mount in water; or pin it to a cork. Examine with a good hand lens, or with the lower power of the microscope.

Construct the floral diagram.

Cross-pollination by insects.—Study the adaptations of the flower for this purpose. The lower lip is the landing place, and the upper lip is the "banner." If there are color markings on any portion of the flower which serve to guide the insect in entering the flower, describe them and note the location. With a needle imitate the entrance of an insect into the flower and determine the way in which cross-pollination takes place.

Compare if possible other members of the mint family in the study of cross-pollination.

Material.—Entire plant with flowers and ripe fruit. If fresh plants are not at hand, those that have been pressed and dried may be used for the study of the entire plant and of the leaves. The flowers may be preserved in formalin.

ORDER PERSONATÆ.

Exercise 80.

439. The figwort family (scrophulariaceæ).—*Toad flax (Linaria vulgaris)*.—The toad flax is widely distributed, growing in waste places as a weed from June to October.

The entire plant.—Note the short, pale green perennial root stock ; the longer erect annual stem ; is it simple or branched? Leaves, form and arrangement.

The inflorescence.—The kind of inflorescence. **The flower.**—What parts of the flower are present? Describe the different parts. **The calyx.**—How many sepals indicated? what is the form of the calyx? **The corolla.**—Form. How many petals indicated? Describe the form of the corolla and its parts. **The stamens.**—How many, their position, size? What is the significance of the difference in the size of the stamens? **The pistil.**—Form, parts ; form of the ovary ; how many carpels present in the pistil?

Study the adaptation of the flower for cross-pollination by the aid of insects ; the lower lip of the corolla as a landing place ; since insects are supposed to be attracted by bright colors, what portion of the flower serves thus to direct the insect?

Note the spur on the corolla, and the nectar inside ; what kinds of insects visit this flower? Imitate with the end of a pencil the entrance of an insect in a flower and endeavor to make out how cross-pollination takes place.

Seed distribution.—Examine ripe seed pods, dry some of them, and then take some of the dry ones and place in water. Describe the action of the pod in scattering the seeds, and the causes.

Other members of the family are interesting to compare with the toad flax, as the beard tongue (Penstemon pubescens), turtle head (Chelone glabra), monkey flower (Mimulus ringens), etc.

Material.—Entire plants with the underground stems. Flowers and fruit. If fresh material cannot be had at the time of the study, dried plants (pressed) will answer for the study of the entire plant. Flowers may be preserved in formalin ; fruits dry.

CHAPTER XLVI.

DICOTYLEDONS (Concluded).

Order Aggregatæ.

440. Lesson XX. The composite family (compositæ).—In all the composites, the flowers are grouped (aggregated) into "heads," as in the sunflower, where each head is made up of a great many flowers crowded closely together on a widened receptacle. The family is a large one, and is divided into several sections according to the kinds of flowers and the different ways in which they are combined in the head. In the asters there is one common type illustrated in fig. 238 by the *Aster novæ-angliæ*. In the aster, as is well shown in the figures, the head is composed of two kinds of flowers, the tubular flowers and the ray flowers. In the tubular flowers the corolla is united to form a slender tube, which is five-notched at the end, representing the five petals. In the ray flowers the corolla is extended on one side into a strap-shaped expansion. Together these strap-shaped corollas form the "rays" of the head. The corolla is split down on one side, which permits the end then to expand and form the "strap." This is a *ligula*, or more correctly speaking a *false ligula*. In fact the ray flower is *bilabiate*. By counting the "teeth" of the false ligula there are found only three, which indicates that the strap here is made up of only three parts of the 5-merous corolla. The two other limbs of the corolla are rudimentary, or suppressed, on the opposite side of the tube. True ligulate flowers are found in the chicory, dandelion, or in the hieracium, where the five points are present on the end of the ligula.

441. The pappus and syngenecious stamens.—The calyx tube in the aster, as in all of the composites, is united with the ovary, while the limb is free. In the aster, as in many others, the limb is divided into slender bristles, the *pappus.* (In some of the composites the pappus is in the form of scales.) The stamens are united by their anthers into a tube (syngenecious) which closely surrounds the style. (In ambrosia the anthers are sometimes distinct.) The style in pushing through brushes out some of the pollen from the anthers and bears it aloft as in the bell-flower, but the stigmatic surface is not yet mature and

Fig. 238.
Aster novæ-angliæ.

Fig. 239.
Head of flowers of Aster novæ-angliæ.

expanded, so that close pollination cannot take place. There are usually no stamens in the ray-flowers. The ovary is composed of two carpels, as is shown by the two styles, but there is only one locule, containing an erect, anatropous, ovule.

The floral formula for the composite family then is as follows: Ca5, Co5, A5, G2.

Fig. 240.
Ray flower of Aster novæ-angliæ.

Fig. 241.
Tubular flower of aster.

Fig. 242.
Tubular flower opened to show syngenecious stamens.

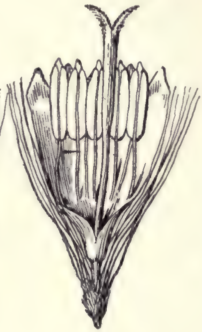


Fig. 243.
Syngenecious stamens opened to show style and two stigmas.

442. Other composites.—The rattlesnake-weed (Hieracium venosum) is an example of another type, with only one kind of flower in the head, the true ligulate flower. The hawk-weed, or devil's paint-brush (H. aurantiacum) is a related species, which is a troublesome weed. The dandelion and prickly lettuce are also members of the ligulate-flowered composites. A number of the composites have only tubular flowers, as in the thoroughwort (eupatorium) and everlasting (antennaria).

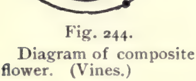


Fig. 244.
Diagram of composite flower. (Vines.)

443. The composites are the most highly developed plants.—The extent to which the union of the parts of the flower has been carried in the composites, and the close aggregation of the flowers in a head, represent the highest stage of evolution reached by the flowers of the angiosperms.

Exercise 81.

444. The aster (Aster novæ-angliæ).—(Some other species may be selected if it is more convenient.) See Exercise 82.

The entire plant.—Describe the entire plant; the character of the stem; the position of the leaves; their form on different portions of the stem; their attachment to the stem. Compare the "radicle" leaves with the stem leaves.

The inflorescence.—Describe the inflorescence, and the position of the flower heads.

A single head of flowers.—Describe the involucre. What different kinds of flowers are present? What is the position of each kind on the head? Determine the approximate number of each kind of flowers in a head.

The ligulate flowers.—Remove one from the head and sketch it, showing the different parts. How many petals are indicated in the strap? How many petals are in the tubular portion of the ligulate flower? Is this a true ligula? Why? Is the calyx present, and what represents it? Split open the corolla tube, and determine whether or not the stamens are present. Is the pistil present in the ligulate flower?

The tubular flowers.—Describe the corolla. How many petals are indicated in the corolla tube? What is such a corolla called?

The stamens.—Split open the corolla tube down one side, and sketch to show the position of the stamens, and their relation to each other. Split open the anther column, spread it out, and sketch to show the relation of the stamens to each other, and the pistil within.

Material.—Entire plants in flower; also some of the mature fruit heads.

Exercise 82.

445. The goldenrod (solidago).—(As an alternate if desired, for Exercise 81.)

If it is desired to study the goldenrod instead of the aster, it will be well to make a comparison with the aster, and the account of the aster here given will serve as a guide for the study of the goldenrod. The daisy is also a good one to compare with the aster, and the outline for the study of the aster here given will answer for the basis of such a study.

Exercise 83.

446. The dandelion (Taraxacum dens leonis).

The entire plant.—Note the very short stem (the plant is sometimes said to be acaulescent, but it has a short stem). Note the thick root; the position of the leaves (often called radicle leaves because of their position on the short stem so near the roots). Sketch a leaf to show its form.

The inflorescence.—What is the kind of inflorescence? Note the leafless stem (flowering scape) which bears the head of flowers. Cut across the stem and split it, and then describe its character.

The involucre.—How many whorls of bracts are there in the involucre? Comparing plants in flower and at different stages of maturity, describe the different positions of the involucre.

The flowers.—Are all the flowers strap-shaped? Note the ligula. Why is it a true ligula? Describe and sketch a single flower.

The calyx.—What represents the calyx? Describe the free portion, or limb. What is the insertion of the calyx?

The corolla.—What represents the corolla, and how many petals are indicated?

The stamens.—What is the relation of the stamens to each other? What is the name applied to such stamens? Sketch a few of the stamens to show their relation to each other.

The pistil.—How many carpels are represented in the pistil? What is the indication of this? What is the relation of the different sets of the flower to each other, and what is their insertion? Give the names applied to these different relations.

The fruit.—Comparing the different stages of the ripening seed, describe the changes which take place in the different parts of the flower and head. What parts of the flower are united in the fruit? What is such a fruit called? How many seeds in the fruit?

Seed distribution.—How are seeds of the dandelion adapted for seed distribution? Take a head of ripe seeds, and blow upon it. Note how the seeds float; observe which end falls first upon the ground (see chapter on seed distribution in Ecology).

Cross-pollination.—In some of the composites, as in the daisy, or in the sunflower, determine what provision is present for cross-pollination. Do all the flowers "blossom" at the same time in a single head? Which ones blossom first? Do the stamens ripen and emerge from the throat of the corolla at the same time as the stigma in the same flower? Why? Compare the dandelion in these respects.

Material.—Entire plants, with flowers (they can be obtained all through the spring); heads of fruit in different stages of maturity.

ECOLOGY.

INTRODUCTION.

447. Life processes in the individual plant.—In studying the phenomena of plant life which relate to the methods of absorption and transportation of food to different parts of the plant, and the internal processes of metabolism concerned in the building up of new plant material, and the formation of waste, as well as certain of the growth phenomena and irritable properties, we have been dealing largely with the individual plant. A study of these life processes we term *physiology*. They relate to the *immediate* conditions of existence and well being of the plant.

448. Form in members of the plant body.—Beyond the very simple plants of the lower groups, and a few reduced forms among the higher plants, the plant body becomes more or less bulky or enlarged, and each cell is so situated that it is unable to participate equally in a number, or all, of the life processes. The plant body therefore becomes more or less differentiated into parts, which from the standpoint of physiology are organs for the performance of distinct functions. This leads us in the complex plant body to recognize *form* as an important correlative of function in many cases. The immense variation which has, through time, taken place in the development of plants has resulted in a great diversity of form even in the same members of the plant body. Within certain limits, however, the form of the plant parts among the individuals of a species is the same, and they are inherited by, or handed down to, the offspring.

449. Form as indicating relationship.—Where the form of a member is a constant peculiarity of the plants of one kind, differences in form among other plants indicate that there are other kinds, or species, of plants. So that aside from the relation which the members of the plant, as organs, bear to the immediate life functions, the *form* of the members becomes the *measure of the value of relationships among kinds.* The study of form in this connection we term *morphology.*

450. Relation of physiology and morphology.—While physiology and morphology are regarded as distinct subjects, still we see how they are interrelated when we consider the details of one or the other subject. It is in the broader concept that the two subjects are fundamentally different.

451. Form and function in a broader sense than the individual.—Just as the individual life processes relate chiefly to the immediate conditions of existence of the plant, and as the individualized form of the members relates to the immediate conditions of relationship; so the life processes in general, on a grand scale or as affected by seasons, or mutual relations, as well as form on a grand scale, relate to more extended conditions of existence, and to relationships, the measure of which is not the form of the plant itself, but the form of the plant community, showing a relationship of different kinds under like conditions of existence. In this sense we are concerned with those processes and forms which are influenced by, or lay hold on, *environment.* By the environment is meant all the surrounding objects, conditions, and forces operating in nature, either temporary, seasonal, or permanent.

452. Mutual and environmental relationships.—While we are engaged with the study of the life processes concerned in nutrition and growth of plants, with the details of form, structure, and systematic relationship, we should not overlook the mutual relationships which exist among plants in their natural habitat, and the phenomena of growth recurring with the seasons, and influenced by environment, or due to inherent

qualities. By a study of the life histories of plants, their habits and behavior under different conditions of environment, we shall broaden our concept of nature and cultivate our æsthetic, observational, and reasoning faculties. The subject is too large for full treatment within the limits of a part of an elementary book. The way here can only be pointed out, and the few examples and illustrations, it is hoped, will serve to open the book of nature to the young student, and lead him to study some of the problems which are presented by every region. This study of plants, in their mutual and environmental relationships, is *ecology*.

453. Some of the factors of environment.—In carrying on studies of this kind one should bear in mind the factors which influence plants in these relationships, that is, what are called the *ecologic factors;* in other words, those agencies which make up the environmental conditions of plants, all of which play a greater or lesser rôle in the habit or status of the plant concerned, and which, acting on all plants concerned, give the peculiar color or physiognomy to the plants of a region or of a more restricted community.

Such factors are climate, with its modifying meteorological conditions; texture, chemistry, moisture content, covering, topography, exposure, etc., of the soil; influence of light and heat; of animals, of plants themselves, and so on.

454. Suggestions for outdoor studies. — For beginning classes, where only a small part of the time is available, excursions can be made from time to time during the year for this purpose, taking certain subjects for each excursion. For example, in the autumn one may study means for the dissemination of seeds, protection of seeds, plant formations, zonal distribution of plants, formation of early spring flowers, etc.; in the winter, twigs and buds, protection of plants against the cold; and in the spring, opening of the buds and flowers, pollination, etc., and further studies on plant societies, relation of plants to soil, topography, etc.

455. Topics for ecological study.—Some of the topics for ecological study and observation which can be taken up by beginning classes are suggested here. The order in which they may be taken up for study may be dependent to a large extent on the time of the year at which the study is made, and also upon the nearness of the school to the supply of material. But in any place, even in large cities, there are abundant supplies of material for several topics, and by foresight preparation can be made in advance for others.

STUDIES IN PERENNIAL SHOOTS, the annual growth as determined by the ring scars, or position of branches.

Trees.

Trees with the main shoot continued through as a central trunk, as in the pines, spruces, larches, etc.

Trees with a deliquescent trunk, where the main shoot is lost by continual branching, as in the elm, etc.

External character of the bark of different trees, and the variation in character of the bark of certain species at different ages.

Branching of shoots, different types of, in trees, shrubs.

Underground shoots, as in certain ferns like the brake, sensitive fern, where long horizontal shoots are formed, or in the mandrake, the toothwort, etc.

Creeping shoots or runners, or trailing shoots as in the polypody, the strawberry plant, the clematis, grape vine, club mosses, and others.

Perennial underground shoots which bear aerial annual shoots, as in trillium, the mandrake, jack-in-the-pulpit, blood-root, etc. Many of these shoots also contain stored nutriment for the growth of the annual shoot.

STUDIES OF LEAF ARRANGEMENT can be made from the bare shoots by observing the positions of the leaf scars.

STUDIES OF BUDS AND BUD FORMATION, protection of buds during the winter, opening of the buds.

Studies in the Relation of Plants to Light.

Direction of shoots with reference to the source of light; compare shoots which have illumination equally on all sides with those which are lighted on one side only.

Direction of branches with reference to the source of light; compare the branching of a tree which has grown in an open field with one of the same species which has grown in the forest (in the forest the lower limbs die away when they are quite small because the overgrowth of foliage at the top of the trees shuts out the light); compare also the branching of trees at the edge of a forest, or at the edge of a clump of trees where one side is strongly lighted and the other side is shaded by the adjacent trees.

Leaf position with reference to access of light can be studied during the season when the shoots are clothed with foliage.

Compare positions of leaves on trees when the foliage is dense; the leaves are nearly on the periphery of the tree, or at the ends of the branches. Sometimes even in the same species, when the foliage is thin at the ends of the branches, a great development of leaves and young shoots through the centre of the tree takes place.

Compare position of leaves with reference to position of sun at different times of day. On some species the leaves are strongly turned, to face the sun, while on others the upper leaf surface faces the field of diffused light. Compare the compass plant (Lactuca scariola).

Compare positions of leaves on prostrate stems, and on the upright branches of the same.

Compare the lengths of petioles when leaves are clustered at the base of the shoot, or on a short shoot.

Compare the positions of the flowers on trees and other plants with varying density of foliage.

Studies in the Relation of Plants to Water. (Water is one of the most important factors in influencing plant life.)

During the growing season observe the effect on different

plants in the variation of water-supply; for example in dry periods when the soil becomes dry, observe how much more quickly some plants wilt than others on bright days. Observe the difference in the character of the leaves of these different plants, and determine what peculiarity of the leaf in the one case favors the loss of water, while in the other case water is conserved, or the leaf does not lose water readily.

With reference to the adaptations of plants to the giving off of water, or of conserving water, Shimper divides them into three classes:

1. The Xerophytes; plants which love dry places, or usually grow in dry places. They possess means for conserving water, or for checking rapid transpiration. The plants are either perennial or annual, and the leaves are not easily wilted. In some of the plants the leaves are absent, or rudimentary or reduced to spines, as in the cacti. The larger number of the xerophytes occur in dry regions.

   Xerophytic structures. Some of the xerophytic structures are thick and succulent stems, or leaves; leaves with a thick cuticle, with a thickened epidermis; covering for the leaf, or stem, in the form of hairs or scales; narrow thick leaves; inrolled edges of leaves; the stomates are often protected by being sunk in deep cavities.

2. The Hygrophytes; plants which love damp situations, or grow in damp or wet situations. They possess means for giving off water, or for ready transpiration; there is a large water content usually in the tissues. Hygrophytes are perennial or annual. The leaves are easily wilted.

3. The Tropophytes; the plants usually grow in temperate regions. They possess means for conserv-

ing water at some seasons and for losing water at others. The plants are all perennial. The perennial parts are xerophytic, while the annual parts are hygrophytic. Examples: trees and shrubs which possess foliage leaves in summer and in the winter the shoots are devoid of leaves. The plants are thus enabled to *turn* from one condition to another. (The first part of the word *tropophyte* means to *turn*, while the latter part means *plant.*) Compare such plants as trillium, jack-in-the-pulpit, etc., with underground perennial shoots, and aerial annual shoots.

The pines, spruces, etc., are protected from rapid transpiration during the winter by having narrow and thick leaves, and also by some internal changes in the leaf as winter comes on.

This division of plant forms into classes as *xerophytes*, *hygrophytes*, and *tropophytes* is often very marked in wide regions. The coastal plains and the mountain regions of the tropics are characterized by hygrophytes; the steppes, deserts, polar regions, and alpine regions of the temperate zones by xerophytes; while the greater part of the North Temperate zone is characterized by tropophytes.

Between these classes there are intermediate forms which break down any attempt to draw a hard and fast line between them; yet such a classification, even if it is arbitrary, is convenient. Also the plants of one class may occur in regions where another class is dominant. For example, the touch-me-not (impatiens) is a hygrophyte, and it occurs in the region dominated by the tropophytes. The parsley (portulaca), the mullein (verbascum) are xerophytes, and they also occur in the same region; while the heaths, the labrador tea, etc., which occur in sphagnum moors are also xerophytes, and yet occur in the region dominated by the tropophytes. (See Chapter LII.)

STUDIES IN THE RELATION OF PLANTS TO SOIL.

Observations can be made on the plants occurring on different kinds of soil, as sandy, clay, loam, rocky soil, poor or rich soil, in waste places, uncared parts of fields or gardens, etc.

One very important condition of the soil is its varying physical condition of texture, and the presence of various chemical substances, which influence greatly the character of the vegetation; but this subject could not well form one for study by young students, since a knowledge of the constituents of the soil would be necessary.

Warming divides plants into four classes:

1. Mesophytes, those plants which occupy a middle position with reference to the water-supply.
2. Hydrophytes, those plants which grow in damp or wet situations.
3. Xerophytes, those plants which grow in dry situations.
4. Halophytes, those plants which grow in soil or water which contains an excess of certain salts.

Some soils contain such an abundance of certain salts that only certain plants grow there. These plants are known as halophytes (salt loving). The salt lands in the great Salt Lake basin, the alkaline lands of California, Nebraska, and Dakota may be cited as examples. Certain families of plants, like the goose-foots, are peculiarly adapted to growing in such soil, though there are plants from a number of families which are found in such situations. The great amount of salt in the soil renders the absorption of water difficult by the plant, so these plants are provided with means for checking transpiration, or they would wilt. In this respect the halophytes resemble the xerophytes, and the structures for checking rapid transpiration are similar. The plants growing in the salt water are also halophytes, and those which have parts that are constantly out

of the water, also possess xerophytic structures for the purpose of checking transpiration.

STUDIES OF PLANTS IN THEIR RELATION TO ANIMALS.

Studies in cross-pollination by the aid of insects would come under this head.

STUDIES IN POLLINATION brought about in other ways.

STUDIES OF NUTRITION as shown in parasitic plants, in symbiosis, etc. (See Chapter XV.)

STUDIES IN THE RELATION OF LIFE HISTORIES of plants to seasonal changes as suggested in Chapter XXXVIII. Compare in this respect plants which flower at different seasons of the year.

STUDIES IN THE STRUGGLE BETWEEN PLANTS for the occupation of the land. (See Chapter XLVIII.)

STUDIES IN SOIL FORMATION by plants. (See Chapter L.)

STUDIES IN ZONAL DISTRIBUTION of plants and in plant communities. (See Chapter XLIX.)

STUDIES IN THE RELATION OF PLANTS TO CLIMATE. (See Chapter LII.)

456. Suggestions.—Brief discussions of a few of these topics are given here to suggest how such studies may be carried on with young pupils. For a fuller discussion of the topics enumerated above, the student is referred to the author's larger "Elementary Botany" and to the works dealing more largely with the subject of ecology cited in the Appendix. But it should be borne in mind that the beginning student cannot in a few excursions make any systematic ecological study, since some special knowledge of botany would be necessary as a foundation. Some of the general truths, however, can be observed.

CHAPTER XLVII.

SEED DISTRIBUTION.

457. Means for dissemination of seeds.—During late summer or autumn a walk in the woods or a field often convinces us of the perfection and variety of means with which plants are provided for the dissemination of their seeds, especially when we discover that several hundred seeds or fruits of different plants

Fig. 245.
Bur of bidens or bur-marigold, showing barbed seeds.

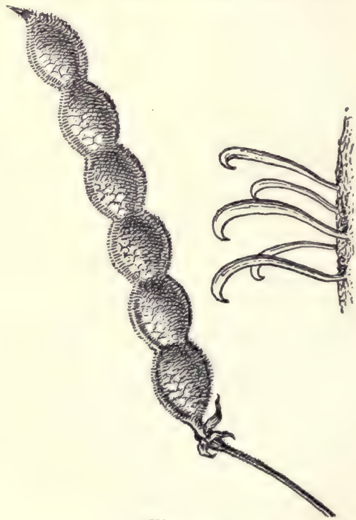


Fig. 246.
Seed pod of tick-treefoil (desmodium); at the right some of the hooks greatly magnified.

are stealing a ride at our expense and annoyance. The hooks and barbs on various seed-pods catch into the hairs of passing animals and the seeds may thus be transported considerable distances. Among the plants familiar to us, which have such contrivances for unlawfully gaining transportation, are the

beggar-ticks or stick-tights, or sometimes called bur-marigold (bidens), the tick-treefoil (desmodium), or cockle-bur (xanthium), and burdock (arctium).

458. Dissemination by water.—Other plants like some of the sedges, etc., living on the margins of streams and of lakes, have seeds which are provided with floats. The wind or the flowing of the water transports them often to distant points.

459. Dissemination by animals.—Many plants possess attractive devices, and offer a substantial reward, as a price for

Fig. 247.
Seeds of geum showing the hooklets where the end of the style is kneed.

the distribution of their seeds. Fruits and berries are devoured by birds and other animals; the seeds within, often passing unharmed, may be carried long distances. Starchy and albuminous seeds and grains are also devoured, and while many such seeds are destroyed, others are not injured, and finally are lodged in suitable places for growth, often remote from the original locality. Thus animals willingly or unwillingly become agents in the dissemination of plants over the earth. Man in

the development of commerce is often responsible for the wide distribution of harmful as well as beneficial species.

460. Mechanisms for ejecting seeds.—Other plants are more independent, and mechanisms are employed for violently ejecting seeds from the pod or fruit. The unequal tension of the pods of the common vetch (Vicia sativa) when drying causes the valves to contract unequally, and on a dry summer day the valves twist and pull in opposite directions until they suddenly

Fig. 248.

Touch-me-not (Impatiens fulva); side and front view of flower below; above unopened pod, and opening to scatter the seed.

snap apart, and the seeds are thrown forcibly for some distance. In the impatiens, or touch-me-not, as it is better known, when the pods are ripe, often the least touch, or a pinch, or jar, sets the five valves free, they coil up suddenly, and the small seeds are whisked for several yards in all directions. During autumn, on dry days, the pods of the witch hazel contract unequally, and the valves are suddenly spread apart, when the seeds, as from a catapult, are hurled away.

Other plants have learned how useful the "wind" may be if

the seeds are provided with "floats," "parachutes," or winged devices which buoy them up as they are whirled along, often miles away. In late spring or early summer the pods of the willow burst open, exposing the seeds, each with a tuft of white hairs making a mass of soft down. As the delicate hairs dry, they straighten out in a loose spreading tuft, which frees the individual seeds from the compact mass. Here they are caught by currents of air and float off singly or in small clouds.

461. The prickly lettuce. — In late summer or early autumn the seeds of the prickly lettuce (Lactuca scariola) are caught up from the roadsides by the winds, and carried to fields where they are unbidden as well as unwelcome guests. This plant is shown in fig. 249.

Fig. 249.
Lactuca scariola.

462. The wild lettuce.—A related species, the wild lettuce (Lactuca canadensis) occurs on roadsides and in the borders of fields, and is about one meter in height. The heads of small yellow or purple flowers are arranged in a loose or branching panicle. The flowers are rather inconspicuous, the rays projecting but little above the apex of the enveloping involucral bracts, which closely press together, forming a flower-head more or less flask-shaped.

At the time of flowering the involucral bracts spread somewhat at the apex, and the tips of the flowers are a little more prominent. As the flowers then wither, the bracts press closely together again and the head is closed. As the seeds ripen the bracts die, and in drying bend outward and downward, hugging the flower stem below, or they fall away. The seeds are thus exposed. The dark brown achenes stand over the surface of the receptacle, each one tipped with the long slender beak of the ovary. The "pappus," which is so abundant in many of the plants belonging to the composite family, forms here a pencil-like tuft at the tip of this long beak. As the involucral bracts dry and curve downward, the pappus also dries, and in doing so bends downward and stands outward, bristling like the spokes of a fairy wheel. It is an interesting coincidence that this takes place simultaneously with the pappus of all the seeds of a head, so that the ends of the pappus bristles of adjoining seeds meet, forming a many-sided dome of a delicate and beautiful texture. This causes the beaks of the achenes to be crowded apart, and with the leverage thus brought to bear upon the achenes they are pried off the receptacle. They are thus in a position to be wafted away by the gentlest zephyr, and they go sailing away on the wind like a miniature parachute. As they come slowly to the ground the seed is thus carefully lowered first, so that it touches the ground in a position for the end which contains the root of the embryo to come in contact with the soil.

463. The milkweed, or silkweed.—The common milkweed,

or silkweed (Asclepias cornuti), so abundant in rich grounds, is attractive not only because of the peculiar pendent flower

Fig. 250.
Milkweed (Asclepias cornuti); dissemination of seed.

clusters, but also for the beautiful floats with which it sends its seeds skyward, during a puff of wind, to finally lodge on the earth.

464. Means for floating the seeds.—The large boat-shaped, tapering pods, in late autumn, are packed with oval, flattened, brownish seeds, which overlap each other in rows like shingles on a roof. These make a pretty picture as the pod in drying splits along the suture on the convex side, and exposes them to view. The silky tufts of numerous long, delicate white hairs on the inner end of each seed, in

drying, bristle out, and thus lift the seeds out of their enclosure, when they are borne, buoyant as vapor, bearing the embryo plant, which is to take its place as a contestant in the battle for existence.

Fig. 251.
Seed distribution of virgin's bower (clematis).

465. The virgin's bower.—The virgin's bower (Clematis virginiana), too, clambering over fence and shrub, makes a

show of having transformed its exquisite white flower clusters into grayish-white puffs, which scatter in the autumn gusts into hundreds of arrow-headed, spiral plumes. The achenes have plumose styles, and the spiral form of the plume gives a curious twist to the falling seed (fig. 251).

CHAPTER XLVIII.

STRUGGLE FOR OCCUPATION OF LAND.

466. Retention of made soil.—In the struggle of plants for existence, there are a number of species which stand ready to rush in where new opportunities present themselves by changed conditions, or by newly made soil. The permanent drainage of ponds or marshes brings changed conditions, and the flora there undergoes remarkable transformations. The deposits of the washings of streams in protected places along the shores, or at their mouths, where deltas or lateral plateaus are made by the accumulations of soil scoured off the banks of the stream, or washed off the fields during rains, make new ground. With such banks of newly made ground are deposited seeds carried along with the soil, or dropped there by the wind, by birds, or other agencies of seed distribution.

467. Vegetation of sand dunes.—Along the sandy beaches of lakes, or of the ocean, drift piles of the fine sand are formed, which often are moved onward by the wind. The surface particles are moved onward to the leeward of the drift, and so on. The form and location of the sand dune gradually changes. Such drifts sometimes slowly but surely march along over soil where a rich vegetation grows, and over valuable land. Even on these sand dunes there are certain plants which can gain a foothold and grow. When a sufficient number obtain a foothold in such places they retain the sand and prevent the movement of the dune.

468. Reforestation of lands.—When by the action of fire or wind, or through the agency of man, portions of forests are

Fig. 252.
Vegetation on "sand dune," New Jersey Coast. (Photograph by Mr. Gifford Pinchot, N. J Geological Survey.)

partially or completely destroyed, a new set of conditions is presented over these areas. One of the most important is that light is admitted where before towering trees permitted but a limited and characteristic undergrowth to remain. Hundreds of forms, which for years have been dormant, are now awakened from their long sleep, and new and recent importations of seeds, which are constantly rushing in, spring into existence to fill the gap, multiply their numbers, and make more sure the perpetuation of their kind.

469. The weaker ones are overcome.—The earliest to appear are not always the ones to endure the longest, and a battle

Fig. 253.
Abandoned field in Alabama, growing up to broom-sedge and trees. (Photograph by Prof. P. H. Mell.)

royal takes place during years for supremacy. The weaker ones are gradually overcome by the more vigorous, and a new crop of trees, which often springs up in such places, finally usurps again the domain, in the name of the same or of a different species.

470. Feral plants in neglected fields.—Domestic plants pro-

tected by man occupy cultivated fields. When cultivation ceases, or the crop is removed, or the fields are neglected, hundreds of species of feral plants, which are constantly springing up, now flourish, bear seed, and take more or less complete

Fig. 254.
Abandoned field, Alabama, self reforested by pines. (Photograph by Prof. P. H. Mell.)

possession of the soil. Impoverished land, abandoned by man, becomes nurtured by nature. Weeds, grass, flowers spring up in great variety often. Some can thrive but little better than the abandoned crops, while others, peculiarly fitted because of one or another adapted structure or habit, flourish. Crab-grass

and other low-growing plants often cover and protect the soil from the direct rays of the sun, and thus conserve moisture.

Fig. 255.
Self-sown white pine in abandoned orchard; trees 9-20 years old. Near Ithaca. (Photograph by the author.)

The clovers which spring up here and there, by the aid of the minute organisms in their roots, gather nitrogen. The melilotus, the passion flower, and other deep-rooted plants reach down to virgin soil and lift up plant food. Each year plant

remains are added to, and enrich, the soil. In some places grasses, like the broom-sedge (andropogon), succeed the weeds, and a turf is formed.

471. Trees follow weeds and grasses.—Seeds of trees in the mean time find lodgment. During the first few years of their growth they are protected by the herbaceous annuals or perennials. In time they rise above these. Each year adds to their height and spread of limb, until eventually forest again stands where it was removed years before. In the Piedmont section of the Southern States such a view as is presented in fig. 253 represents how abandoned fields are taken by the broom-sedge, to be followed later by pines, and later by a forest as shown in fig. 254.

472. Self-sown white pines.—In New York State many abandoned hillsides are being reforested slowly by nature with the white pine. Fig. 255 represents a group of self-sown pines ranging from three to six meters high (10–20 feet), growing up in an abandoned orchard near Ithaca. In this reforestation of impoverished lands, man can give great assistance by timely and proper planting.

CHAPTER XLIX.

ZONAL DISTRIBUTION OF PLANTS.

473. On the margins of lakes or ponds, where the slope is gradual from the land into the water, one often has an opportunity to study the relation of various plants to different conditions of soil and water. In rowing near the south shore of Lake Cayuga, I have often been impressed with the definite areas occupied by certain plants. Figure 257 is from a photograph, taken from the boat, of the shore distribution of these plants. The most striking feature here is the grouping of certain kinds of plants in definite lines or zones. Here the limitations of the zones are quite distinct, so that the transition from one zone to another is quite abrupt, though there is some mixture of the kinds at the *zone of transition*, or *tension line*.

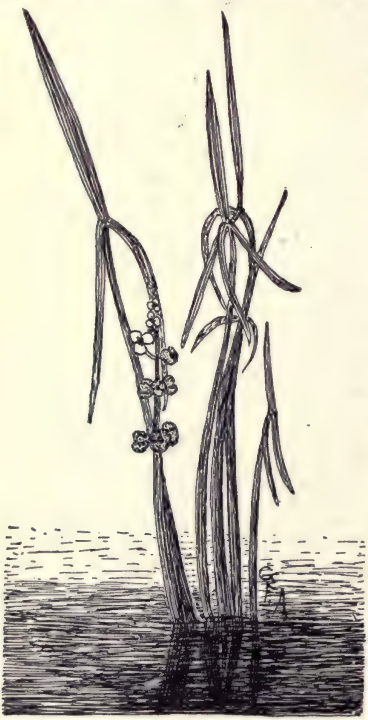


Fig. 256.
Sagittaria variabilis.

474. Zonal arrangement.—This arrangement of plants under such environmental influences is termed "*zonal distribution of plants.*" The slope where this photograph was taken is so

Fig. 257.
Zonal distribution of plants, south shore of Cayuga Lake. See text. (Photograph by the author.)

symmetrical that plants suited by their long habit of growing at certain depths of water, or in soil of a certain moisture content, are readily drawn into zones parallel with the shore line.

Fig. 258.
Sagittaria variabilis.

Several zones can be readily made out in this region; two of them at least do not show in the picture since they are submerged.

475. Submerged zones in the foreground.—If we treat of the

two submerged zones, the first one is in the rear of the point from where the photograph was taken, and consists of extensive areas of chara in four to five meters of water. The second zone

Fig. 259.
Sagittaria heterophylla. Often forms a zone just outside of the Sagittaria variabilis.

then is in the water shown in the foreground of the picture. The plants here are also submerged, or only a small portion reaches the surface of the water, and so the zone does not

show. In this zone occurs the curious Vallesneria spiralis, with its corkscrew flower stem, and various potamogetons.

476. The visible zones.—In the third zone, or the first one which shows in the picture, are great masses of the arrow-leaf (sagittaria) so variable in the form of its leaves. Next is the fourth zone, made up here chiefly of bullrushes (scirpus), and occasionally are clumps of the cattail flag (typha). Behind this is the fifth zone, only to be distinguished at this distance by the bright flower heads of the boneset (Eupatorium perfoliatum) and joepye-weed (Eupatorium purpureum), and the blue vervain (Verbena hastata), which occurs on the land. Willows make a compact and distinct sixth zone, while at the right, the oaks on the hillside beyond form a seventh zone, and still farther back is a zone of white pines, making the eighth.

CHAPTER L.

SOIL FORMATION IN ROCKY REGIONS AND IN MOORS.

Lichens.

477. The lichen, parmelia.—Many of the lichens are small and inconspicuous. They often appear only as bits of color on tree trunk or rock. One of the conspicuous ones on stones lying on the ground is the grayish-green thallus of Parmelia contigua (fig. 260). Its pretty, flattened, forking lobes radiate in all directions, advancing at the margin, and covering year by year more and more of the stone surface. Numerous cup-shaped fruit bodies (apothecia) are scattered over the central area. The thallus clings closely to the rock surface by numerous holdfasts from the under side, which penetrate minute crevices of the rock. The lichen derives its food from the air and water. By its closely fitting habit it retains in contact with the rock certain acids formed by the plant in growth, or in the decay of the older parts, which slowly disintegrate the surface of the rock. These disintegrated particles of the rock, mingled with the lichen débris, add to the soil in those localities.

478. Lichens are among the pioneers in soil making.—The habit which many lichens have of flourishing on the bare rocks fits them to be among the pioneers in the formation of soil in rocky regions which have recently become bared of ice or snow. The retreat of glaciers from peaks long scoured by ice, or the unloading of broken rocks along its melting edge, exposes the rocks to the weathering action of the different elements. Now

the lichens lay hold on them and invest them with fantastic figures of varied color. Disintegrating rock, débris of plants and animals, join to form the virgin soil. Certain of the blue-green algæ, as well as some of the mosses, are able to gain a foothold on rocks and assist in this process of soil formation.

Fig. 260.
Rock lichen (Parmelia contigua).

A view of rocks thrown down by the melting and retreating edge of a glacier in Greenland is shown in fig. 261. These rocks at the time the photograph was taken had no plant life on them. At other places in the vicinity of this glacier, rocks

longer uncovered by ice were being covered by plant life. One of the Greenland rock lichens is shown in fig. 262.

479. Other plants of rocky regions.—Certain of the higher plants also find means of attachment to the bare rocks of the

Fig. 261.
Edge of glacier in Greenland, showing freshly deposited rocks. (From Prof. R. S. Tarr.)

arctic and mountain regions. The roots penetrate into narrow crevices in the rock, and are able to draw on the water which is elevated by capillarity. Such plants, however, which live on bare rocks, whether in the arctic or in mountain regions, have

leaves which enable them to endure long periods of drought. These plants have either succulent leaves like certain of the stone-crops (sedum), or small thick leaves which are closely overlapped as in the Saxifraga oppositifolia.

Few of us, unfortunately, can make the trip to the arctic regions to study these interesting plants which play such an

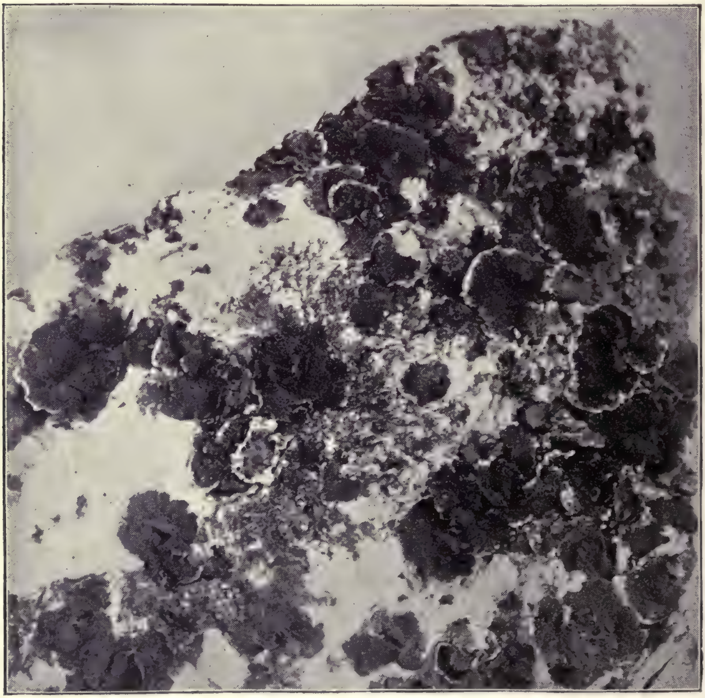


Fig. 262.
Rock lichen (umbilicaria) from Greenland.

important rôle in the economy of nature. Rocky places, however, or loose stones are common nearer home. Observation of their flora, and the means by which such plants derive nutriment, store moisture, or protect themselves from drought, will well repay outdoor excursions.

Fig. 263.
Atoll moor, showing central pond, elevated ring, and ditch at original shore line. Near Ithaca. (From photograph by the author.)

480. Filling of ponds by plants.—Not only are plants important agencies in the formation of soil in rocky regions, they are slowly but surely playing a part in the changes of soil and in the topography of certain regions. This is very well marked in the region of small ponds, where the bottom slopes gradually out to the deeper water in the centre. Striking examples are sometimes found where the surface of the country is very broken or hilly with shallow basins intervening. In what are termed morainic regions, the scene of the activity of ancient glaciers, or in the mountainous districts, we have opportunities for studying plant formations, which slowly, to be sure, but nevertheless certainly, fill in partly or completely these basins, so that the water is confined to narrow limits, or is entirely replaced by plant remains in various stages of disintegration, upon which a characteristic flora appears.

481. A plant atoll.—In the morainic regions of central New York there are some interesting and striking examples of the effects of plants on the topography of small and shallow basins. These formations sometimes take the shape of "atolls," though plants, and not corals, are the chief agencies in their gradual evolution. Fig. 263 is from a photograph of one of these plant atolls about 15 miles from Ithaca, N. Y., along the line of the E. C. & N. R. R. near a former flag station known as Chicago. The basin here shown is surrounded by three hills, and is formed by the union of their bases, thus forming a pond with no outlet.

482. Topography of the atoll moor.—The entire basin was once a large pond, which has become nearly filled by the growth of a vegetation characteristic of such regions. Now only a small, nearly circular, central pond remains, while entirely around the edge of the earlier basin is a ditch, in many places with from 30–60*cm.* of water. There is a broad zone of land then lying between the central pond and the marginal ditch. Just inside of the ring formed by the ditch is an elevated ring extending all around, which is higher than any other part

of the atoll. On a portion of this ring grow certain grasses and carices. The soil for some depth shows a wet peat made up of decaying grasses, carices, and much peat moss (sphagnum). In some places one element seems to predominate, and in other cases another element. On some portions of the outer ring are shrubs one to three meters in height, and occasionally small trees have gained a foothold.

Next inside of this belt is a broad, level zone, with Carex filiformis, other carices, grasses, with a few dicotyledons. Intermingled are various mosses and much sphagnum. The soil formation underneath contains remains of carices, grasses, and sphagnum. This intermediate zone is not a homogeneous one. At certain places are extensive areas in which Carex filiformis predominates, while in another place another carex, or grasses predominate.

483. A floating inner zone.—But the innermost zone, that which borders on the water, is in a large measure made up of the leather-leaf shrub, *cassandra*, and is quite homogeneous. The dense zone of this shrub gives the elevated appearance to the atoll immediately around the central pond, and the cassandra is nearly one meter in height, the "ground" being but little above the level of the water. As one approaches this zone, the ground yields, and by swinging up and down, waves pass over a considerable area. From this we know that underneath the mat of living and recent vegetation there is water, or very thin mud, so that a portion of this zone is "floating."

The inner, or cassandra, zone is more unstable, that is, it is all "afloat," though firmly anchored to the intermediate zone. The roots of the shrubs interlace throughout the zone, firmly anchoring all parts together, so that the wind cannot break it up. Between the tufts of the cassandra are often numerous open places, so that the water or thin mud on which the zone floats reaches the surface, and one must exercise care in walking to prevent a disagreeable plunge. No resistance is offered

Fig. 264.

One side of atoll moor, showing two elevated zones of made land from marginal ditch to central pond. (Photograph by the author.)

to a pole two or three meters long in thrusting it down these holes. Grasses, carices, mosses, sphagnum, and occasionally moor-loving dicotyledons occur, anchored for the most part about the roots of the cassandra. Standing at the inner margin of the cassandra zone, one can see the mud, resembling a black ooze, formed of the titrated plant remains, which have floated out from the bottom of the older formations. In some places this lies very near the surface, and then certain aquatic plants like bidens, and others, find a footing. Upon this black ooze the formation can continue to encroach upon the central pond. Agitated by the wind, more and more of the ooze passes outward, so that in time there is a likelihood that the pond will cease to exist, yielding, as it has in other places, the right of possession to the contentious vegetation.

484. How was the atoll formed?—In the early formation of the atoll, it is possible that certain of the water-loving carices and grasses began to grow some distance (three to four meters) from the shore, where the water was of a depth suited to their habit. The stools of these plants gradually came nearer the surface of the water. As they approach the surface, other plants, not so strong-rooted, like mosses, sphagnum, etc., find anchorage, and are also protected to some extent from the direct rays of sunlight. Partial disintegration of the dead plant parts and mingling with the soil gradually fill on the inside of the zone, so that the depth of the water there becomes less. Now the zone of the carices can be extended inward.

The continued growth of the sphagnum and the dying away of the lower part of the plant add to the bulk of the plant remains in the zone, and finally quite a firm ground is formed, shutting off the shallow water near the shore from the deeper water of the pond. As time goes on other plants enter and complicate the formation, and even make new ones, as when the cassandra takes possession.

The original pond here was rather oblong, and one end possibly much shallower than the other, so that it filled in much

more rapidly, leaving the central pond at the east end. Over a portion of the west end there is an extensive cassandra formation, with some ledum (labrador tea), but separated from the circular cassandra zone by an intermediate zone. In this end-cassandra formation other shrubs, and white pines five to fifteen years old, are gaining a foothold, and in a quarter of a century or more, if left undisturbed, one may expect considerable changes in the flora of this atoll. It is possible that a rise of the water for a number of years when the earlier zones were floating accounts for the circular elevation and atoll formation, or that the dense shade from forest trees years ago may have checked the growth of plants in the margin, thus leaving a marginal depression.

485. A black-spruce moor.—A somewhat similar but more advanced plant formation occurs east of Freeville, N. Y., and about nine miles distant from Ithaca. The centre of the basin, which was perhaps shallower than the former one, has become completely filled, and all of the central formation is more elevated than the margin by the shore of the basin. All around the margin in wet weather the ground is more or less submerged, while all the central portion is so elevated that the numerous stools or hummocks of grasses like eriophorum, with its white tufts sparkling in the sunlight like a firmament of stars, shrubs like cassandra, pyrus, nemopanthes, etc., support one in walking above the water which rises in the intervening spaces. Sphagnum, polytrichum, and other mosses grow, especially in the stools of the other plants, where they now are shaded by the larger growth, and in drier seasons catch the water which trickles down during rain.

Years ago the forest encroached on this formation, and trees of the hemlock-spruce, black spruce, larch, etc., of considerable size gained a footing, first along the margin, then along the more elevated zone a short distance within. The black spruce trees spread all over the centre of the formation, attaining a height of one to six or eight meters, while the trees of the

marginal zone where they first entered, and the ground is somewhat more elevated, attained a much greater height.

486. Fall of the trees on the marginal zone when the wind break was removed.—These large trees of the marginal zone, though they were rooted to a great extent in loose soil, nevertheless were protected from winds by the forests on the surrounding hills. When, however, these hills on three sides were cleared for cultivation the wind had full sweep, and many of the large trees were uprooted by the force of the gales. This view is supported by the fact that the west-

Fig 265. Black spruce swamp. Spruce in the centre nearly all dead.

ern hill is still covered by forest, and large spruce trees of the marginal zone are still standing, though several were up-rooted September, 1896, during a fierce southeastern gale, the wind from this direction having full play upon them.

487. Dying of the spruce of the central area.—This removal of the forests from the surrounding hills very likely had its influence in hastening the melting of the winter snows on the hills, so that excessive quantities of water from this source

Fig. 266.
Dying black spruce in moor. (Photograph by the author.)

rushed quickly down into the swamp, flooding it at certain seasons much higher than the normal high-water mark during former times, when the hills were forest-covered. Also during rains the water would now rush quickly down into the swamp, flooding it at these times. This greater quantity of water has had its effect, probably, in causing many of the young spruces over the centre of the formation to die off.

488. Effect of fire.—This may also have been hastened by fires which would now more often sweep over the swamp during dry seasons. In partial evidence of this are many young spruce trees with scars near the ground where the bark has been destroyed. This gives admittance to wood-boring insects which farther aid in the process of weakening and debilitating the trees. The dying off of the lower limbs of these marsh spruces suggests the action of fire, as well as excessive moisture at times. Many of them now present only a small convex top of living branches. It is interesting to observe the gradation in this respect in different trees.

489. Weird aspect of dead spruces.—The weird aspect presented by a clump of these dying young spruce trees is heightened also by the changes in the form of the branches as they die. The living branches have a graceful sigmoid sweep with their free ends curving upwards as in many conifers. As the branches die, the free ends curve downward more and more, all gradations being presented in a single tree. A group of such dying spruce trees is shown in fig. 266. Some have been long dead; only the knotted, weather-beaten trunks still remain tottering to their final condition. Others with leafless, dried, sprawling branches go swirling with every wind, while a few struggle on in the presence of these untoward conditions.

490. Other morainic moors.—In other basins, where the hills on all sides are still forest-clad, more equable temperature and moisture conditions are conserved. This permits plants to flourish here which in the exposed basins are disappearing from the formations or only leading a miserable existence. This is strikingly true of some sphagnum formations. In the atoll formation described the evidence suggests that sphagnum formerly played a more active part in the evolution of that type of moor than has been the case since the hills were denuded of their trees. So also in the spruce moor, sphagnum probably was at one time a prominent factor in the formation of the early vegetation. But excessive drought during certain seasons, and

full exposure to the sun and wind, have served to lessen its influence and importance. But where protected from the wind, to a large extent from the heat of the sun, and supplied with a suitable moisture condition, the sphagnum flourishes. It grows either alone in shallow water, encroaching more and more on the centre of the basin, or follows after and anchors among water-loving grasses and carices. In some cases it may thus largely cover such earlier formations. An examination of the sphagnum plant shows us how well it is adapted to flourish under such conditions. The main axis of the plant bears lateral branches nearly at right angles, but with a graceful downward sweep at the extremity. These primary lateral branches bear secondary branches, which arise, usually several, from near the point of attachment to the main axis. They hang downward, overlap on those below, and completely cover the main axis or stem. The leaves of sphagnum are peculiarly adapted for the purpose of taking up quantities of water. Not all the cells of the leaf are green, but alternate rows of cells become broadened, lose their chlorophyll, and their protoplasm collapses on the inner faces of the cell walls in such a way as to form thickened lines, giving a peculiar sculpturing effect to them. Perforations also take place in the walls. These

Fig. 267.
Two fruiting plants of sphagnum. (From Kerner and Oliver.)

empty cells absorb large quantities of water, and by capillarity it is lifted on from one cell to another. These pendent branches, then, which envelop the sphagnum stem, lift water up from the

Fig. 268.
Where isoetes grows. A small morainic basin near Ithaca. (Photograph by the author.)

moist substratum to supply the leaves and growing parts of the plant which are at the upper extremity.

491. Increase each year.—Year by year the extension of the sphagnum increases slowly upward by growth of the ends of the

individual plants, while the older portions below die off, partly disintegrate, and pass over into the increasing solidity and bulk of the peat. It thus happens sometimes that the centres of

Fig. 269.
Cypress knees, Mississippi. (Photograph by H. von Schrenk.)

such basins or moors are more elevated than the margins, because here a greater amount of water exists in the depths which is pumped up for use by the plants themselves. Such a formation is sometimes called a "high moor."

492. Change in form.—Because of the peculiar topographic features of these basins, together with the conditions of moisture, etc., changes in their form are quite readily observed.

But no less important are the influences of plants on soil conditions on the hills, and in more level areas. Old plant parts, and plant remains, by decay add to the bulk, fertility, and changing texture and physical condition of the soil.

493. The bald cypress (Taxodium distichum).—Very characteristic are the formations presented by the forests of the bald cypress of the South, which grows in swampy or marshy places. The "knees" on the roots of this cypress make grotesque figures in the cypress forest. These take the form of upright, columnar outgrowths, broader at the base or point of attachment to the horizontal root, and possess a fancied resemblance to a knee. These knees are said to occur at points on the horizontal root above and opposite the point where a root branch extends downward into the soft marsh soil. They thus give strength to the horizontal root at the point of attachment of the branch which penetrates into the soft soil, and during gales they hold these root branches more rigidly in position than would be the case if the horizontal root could easily bend at this point. The knees thus are supposed by some to strengthen the anchor formed by the root in the loose soil. Their development may be the result of mechanical irritation at these points on the horizontal root, brought about by the strain on the roots from the swaying of the tree. Others regard them as organs for aerating the portions of the root system which are usually submerged in water or wet soil, and in this sense the knees are sometimes termed pneumatophores. The knees catch and hold floating plant remains during floods, and by the decay of this débris the fertility of the soil is increased.

CHAPTER LI.

PLANT COMMUNITIES: SEASONAL CHANGES.

494. Relations of plants.—One of the interesting subjects for observation in the study of the habits and haunts of plants is the relation of plants to each other in communities. In the topography of the moors, and of the land near and on the margins of bodies of water, we have seen how the adaptation of plants to certain moisture conditions of the soil, and to varying depths of the water, causes those of a like habit in this respect to be arranged in definite zones. Often there is a predominating species in a given zone, while again there may be several occupying the same zone, more or less equally sharing the occupation. Many times one species is the dominant form, while several others exist by sufferance.

495. Plants of widely different groups may exist in the same community.—So it is that plants of widely different relationships have become adapted to grow under almost identical environmental conditions. The reed or grass growing in the water is often accompanied by floating mats of filamentous algæ like spirogyra, zygnema; or other species, as œdogonium, coleochæte, attach themselves to these higher lords of creation; while desmids find a lodging place on their surface or entangled in the meshes of the other algæ. Chara also is often an accompaniment in such plant communities, and water-loving mosses, liverworts, and fern-like plants as marsilia. Thus the widest range of plant life, from the simple diatom or monad to the complex flowering plant, may, by normal habit or adapted form, live side by side, each able to hold its place in the community.

In field or forest, along glade or glen, on mountain slope or in desert regions, similar relationships of plants in communities are manifest. The seasons, too, seem to vegetate, blossom, and fruit, for in the same locality there is a succession of different forms, the later ones coming on as the earlier ones disappear.

496. Seasonal succession in plant communities. — The wooded slopes in springtime teem with trillium, dentaria,

Fig. 278.
Azalea (Rhododendron nudicaulis).

podophyllum, and other vernal blossoms, while on the steeper hillsides the early saxifrage is to be found. In the rocky portions of the glen, which is also a favorite lodgment for this pretty, white saxifrage, the wild columbine loves to linger and dangle its spurred flowers. The lichen-colored ledge is wreathed

Fig. 271.
Walking fern, climbing down a hillside.

with moss and fern. On the partly sunlit slopes the clusters of azalea are radiant with blossoms, while here and there the shad-bush, or service-berry (amelanchier), with its mass of white flower-sprays, overhangs some cliff, and the cockspur thorn (cratægus) vies with it in the profusion of floral display. Near by sheets of water pour themselves unceasingly on the rocks below, scattering spray on the thirsty marchantia. Out from the steep slopes above rise the graceful sprays of the yew (taxus),

Fig. 272.
Spray of kalmia flowers.

shaded by the towering hemlock spruces. The "walking-fern" here, holding fast above, climbs downward by long graceful strides.

497. Change in color with the season.—But the scene shifts, and while these flowers cast their beauty for the season, others put on their glory. The flowering dogwood spreads its decep-

tive bracts as a halo around the clusters of insignificant flowers. The laurel (kalmia) with its clusters of fluted pinkish blossoms is a joy only too brief. Smaller and less pretentious ones abound, like the whortleberries, amphicarpæa, bush-clover (lespedeza), sarsaparilla, and so on.

498. Autumn plants.— In the autumn the glen is clothed with another robe of beauty. With the fall of the "sere and yellow leaf," golden-rod and aster still linger long in beauty

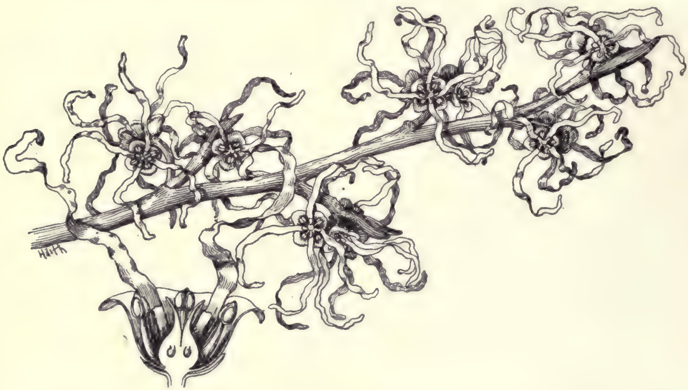


Fig. 273.
Spray of witch-hazel (hamamelis) with flowers; section of flower below.

and profusion. When the leaves have fallen the witch-hazel (hamamelis) begins to flower, and the snows begin to come before it has finished spreading its curled yellow petals.

499. The landscape a changing panorama.—In our temperate regions the landscape is a changing panorama; forest and field, clothed with a changing verdure, don and doff their foliage with a precision that suggests a self-regulating mechanism.

In the glad new spring the mild warmth of the sun stirs the dormant life to renewed activity. With the warming up of the soil, root absorption again begins, and myriads of tiny root hairs pump up watery solutions of nutriment and various salts.

These are carried to the now swelling buds where formative processes and growth elongate the shoot and expand the leaf. Buds long wrapped in winter sleep toss back the protecting scales. In a multitude of ways the different shrubs and trees

Fig. 274.
Opening buds of hickory.

now discard the winter armature which has served so good a purpose, and tiny bud leaves show a multitude of variations from simple bud scale to perfect leaf, a remarkable diversification in which the plant from lateral members of the stem forms

organs to serve such a variety of purpose under such diametrically opposed environmental conditions.

500. Refoliation of bare forests in spring.—There is a

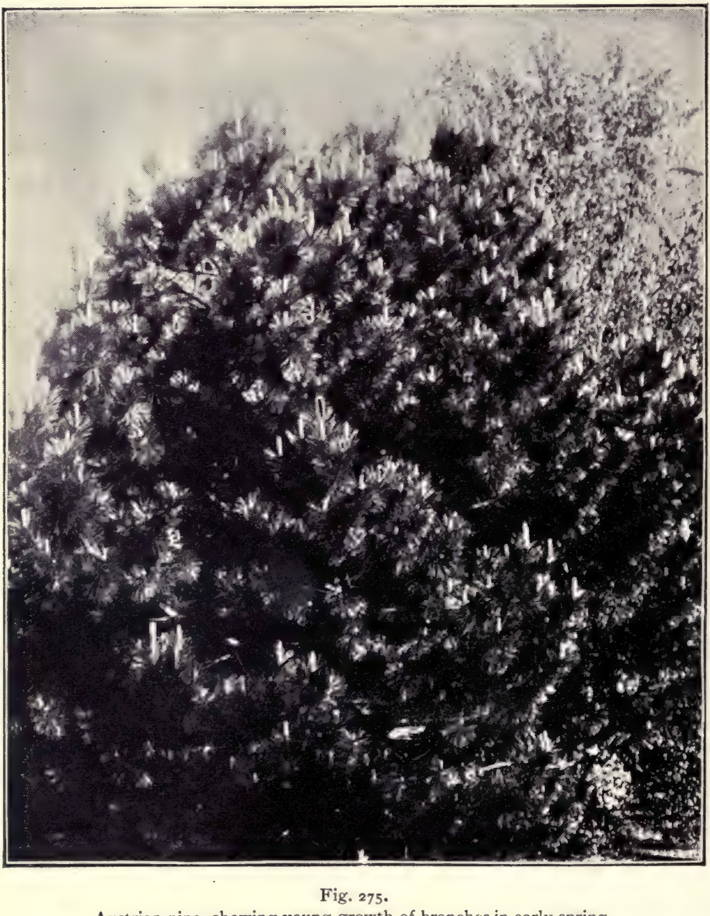


Fig. 275.
Austrian pine, showing young growth of branches in early spring.

certain charm watching the refoliation of the bare forests, when the cool gray and brown tints are slowly succeeded by the light

yellow-green of the young leaves, which presents to us a warming glow of color. Then the snow-clad fields change to gray, and soon are enveloped in a living sea of color. The quiet hum of myriads of opening buds and flowers in harmony with the general awakening of nature, and the trickling streamlets which unite into the gurgling brooks, makes sweet music to our attentive minds.

501. Contrast of color in evergreens.—The evergreens display a striking contrast of color. The leafy, fan-shaped branches of the hemlock-spruce (tsuga) are fringed with the light green of the new growth. The pines lift up numbers of cylindrical shoots, with the leaf fascicles for a time sheathed in the whitened scales, while the shoots are tipped with the brown or flame-colored female flowers, reminding one of a Christmas tree lighted with numerous candles. The numerous clusters of staminate flowers suggest the bundles of toys and gifts, and one inquires if this beautiful aspect of some pines when putting on their new growth did not suggest the idea of the Christmas tree at yule time.

502. The summer tints are more subdued.—As summer time draws on the new needles of the pine are unsheathed, the light green tints of the forest are succeeded by darker and subdued colors, which better protect the living substance from the intense light and heat of midsummer. The physiological processes for which the leaf is fitted go on, and formative materials are evolved in the countless chlorophyll bodies and transported to growing regions, or stored for future use. In transpiration the leaf is the terminus of the great water current started by the roots. Here the nutrient materials, for which the water serves as a vehicle, are held back, while the surplus water evaporates into the air in volumes which surprise us when we know that it is unseen.

503. Autumn colors.—As summer is succeeded by autumn, a series of automatic processes goes on in the plant which fits it for its long winter rest again. Long before the frosts appear,

here and there the older leaves of certain shrubs lose more or less of the green color and take on livelier tints. With the disintegration of the chlorophyll bodies, other colors, which in some cases were masked by the green, are uncovered. In other cases decomposition products result in the formation of new colors. These coloring substances to some extent absorb the sun's rays, so that much of the nitrogenous substances in the leaf may not be destroyed, but may pass slowly back into the stem and be stored for future use.

504. Fall of the leaf.—The gorgeous display of color, then, which the leaves of many trees and shrubs put on is one of the many useful adaptations of plants. While this is going on in deciduous trees, the petiole of the leaf near its point of attachment to the stem is preparing to cut loose from the latter by forming what is called a separative layer of tissue. At this point the cells in a ring around the central vascular bundle grow rapidly so as to unduly strain the central tissue and epidermis, making it brittle. In this condition a light puff of wind whirls them away in eddies to the ground. The frosts of autumn assist in the separation of the leaf from the stem, but play no part in the coloration of the leaf.

As the cold weather of autumn and winter draws slowly on, these trees and shrubs cast off their leaves, and thus get rid of the extensive transpiration surface, or in some cases the dead leaves may cling for quite a long period to the trees. However, in the death and fall of the leaves of these deciduous trees and shrubs, or the dying back of the aerial shoots of perennial herbaceous plants, there is a most useful adaptation of the plant to lay aside, for the cold period, its extensive transpiration surface. For while the soil is too cool for root absorption, should transpiration go on rapidly, as would happen if the leaf surface remained in a condition for evaporation, the plants would lose all their water and dry up.

CHAPTER LII.

ADAPTATION OF PLANTS TO CLIMATE.

505. Some characteristics of desert vegetation.—One of the important factors in plant form and distribution is that of clmate, which is modified by varying conditions, as temperature, humidity of the air, dryness, etc. In desert regions where the air and soil are very dry, and plants are subject to long periods of drought, there is a very characteristic vegetation, and a variety of forms have become adapted to resist the drying action of the climate.

Some of the plants, especially the larger ones, have very succulent stems or trunks, or they are more or less expanded but thickened, while the leaves are reduced to mere spines or hairs, as in the cacti. If plants in desert regions had thin and broadly expanded leaves, transpiration would be so rapid, and so great, as to kill them. In these succulent stems there is a proportionately small surface area exposed, so that transpiration is reduced. The chlorophyll resides here in the stems, and they function as foliage leaves in many other plants do.

Other plants of the desert, which do not have succulent stems, are provided with closely appressed and small, thick, scale-like leaves. The leaves in many of these plants have an epidermis of several layers of cells, so that transpiration does not take place so rapidly. In addition to this the stomata are sunk in pits, or cavities, so that the guard cells are not so exposed to the drying action of currents of air at the surface.

In still other cases the leaves and stems are covered with a dense felt of hairs which serves as a cushion to protect them

from the direct rays of the sun, and also from the fierce blasts of dry air which frequently sweep over these regions. The hairs are so close, and so interwoven, that the air caught in the interstices is not easily displaced, and the leaves are not then subject to the drying effects of the passing winds.

506. Some plants of temperate regions possess characters of desert vegetation.—Even in temperate regions in localities where the climate is more equable, certain plants, strangely, are similarly modified, or provided with protecting armor. The common purslane (portulaca) is an example of a succulent plant, and we know how well it is able to resist periods of drought, even when cut free from the soil. With the oncoming of rains it revives, and starts new growth, while in wet weather cutting it free from its roots scarcely interferes with its growth.

Similarly the common mullein (Verbascum thapsus), the leaves and stems of which are so densely covered with stellate hairs, is able to resist dry periods. One can see how efficient this panoply of trichomes is by immersing the leaves in water. It is very difficult to remove the air from the interstices of the interwoven trichomes so as to wet the epidermis.

507. Alpine plants with desert characteristics.—Alpine plants (those on high mountains), as well as arctic plants, are similarly modified, having usually either succulent stems and leaves, or small, thick and appressed leaves, or leaves covered with numerous hairs. Cassiope, occurring on mountain summits of the northeastern United States, and far northward, has numerous needle-shaped, closely imbricated leaves. The plants need the protection afforded them by these peculiarities in these alpine and arctic regions because of the dry air and winds, as well as because of the bright sunlight in these regions. Because of the bright sunlight in alpine and arctic regions many of the plants are noted for the brilliant colors of the flowers.

508. Low stature of alpine plants a protection against wind and cold.—Another protection to plants from winds and

Fig. 276.
Birch trees from Greenland, one third natural size.

Fig. 277.
Willows from Greenland, one third natural size.

from the cold in such regions is their low stature. Many of the herbaceous plants have very short stems, and the leaves lie close to the soil, the plants and flowers sometimes half covered with the snow. The heat absorbed by the soil is thus imparted to the plant. Trees in such regions (if the elevation or latitude is not beyond the tree line) have very short and crooked stems, and sometimes are of great age when only a foot or more high, and the trunk is quite small. In figure 276 are shown some birch trees from Greenland, one third natural size, the entire tree being here shown. Similarly figure 277 represents some of the arctic willows, one third natural size.

509. Some plants of swamps and moors present characters of arctic or desert vegetation.—Many of the plants of our swamps and moors have the characters of arctic or of desert vegetation, i.e., small, thick leaves, or leaves with a stout epidermis. The labrador tea (Ledum latifolium), an inhabitant of cold moors or mountain woods, has thick, stout leaves with a hard epidermis on the upper side, and the lower side of the leaves is densely covered with brown, woolly hairs. Transpiration is thus lessened. This is necessitated because of the cold soil and water of the moor surrounding the roots, which under these conditions absorb water slowly. Were the leaves broad with a thin and unprotected epidermis, transpiration would be in excess of absorption, and the leaves would wither. Cassandra, or leather-leaf, and chiogenes, or creeping snowberry, are other examples of these shrubs growing in cold moors.

510. Hairs on young leaves protect against cold and wet.—Hairs on young leaves in winter buds afford protection from cold and from the wet. The young leaves of the winter buds of many of our ferns are covered with a dense felt of woolly hairs. In species of osmunda this is very striking. The leaves are quite well formed, though small, during the autumn, and the sporangia are nearly mature. The hairs are so numerous, and so closely matted together, that they can be torn off in the form of a thick woolly cap.

APPENDIX.

COLLECTION AND PRESERVATION OF MATERIAL.

Spirogyra may be collected in pools where the water is present for a large part of the year, or on the margins of large bodies of water. To keep fresh, a small quantity should be placed in a large open vessel with water in a cool place fairly well lighted. In such places it may be kept several months in good condition.

Some species of vaucheria occur in places frequented by œdogonium or spirogyra, while others occur in running water, or still others on damp ground. Frequently fine specimens of vaucheria in fruit may be found during the winter growing on the soil of pots in greenhouses. The jack-in-the-pulpit, also known as Indian turnip, growing in damp ground I have found when potted and grown in the conservatory yields an abundance of the vaucheria, probably the spores of the alga having been transferred with the soil on the plants. When material cannot be obtained fresh for study, it may be preserved in advance in formalin or alcohol.

Wheat rust.—The cluster-cup stage may be collected in May or June on the leaves of the barberry. Some of the affected leaves may be dried between drying-papers. Other specimens should be preserved in 2% formalin or in 70% alcohol. If the cluster cup cannot be found on the barberry, other species may be preserved for study.

The uredospore and teleutospore stages can usually be found abundantly on wheat and oats, especially on late-sown oats

minute black specks on the surface of the leaf. The leaves should be preserved dry after drying under pressure.

Liverworts.

Marchantia.—The green thallus (gametophyte) of marchantia may be found at almost any season of the year along shady banks washed by streams, or on the wet low shaded soil. Plants with the cups of gemmæ are found throughout a large part of the year. They are sometimes found in greenhouses, especially where peat soil from marshy places is used in potting. In May and June male and female plants bear the gametophores and sexual organs. These can be preserved in $2\frac{1}{2}\%$ formalin or in 70% alcohol. If one wishes to preserve the material chiefly for the antheridia and archegonia a small part of the thallus may be preserved with the gametophores, or the gametophores alone.

In July the sporogonia mature. When these have pushed out between the curtains underneath the ribs of the gametophore, they can be preserved for future study by placing a portion of the thallus bearing the gametophore in a tall vial with 2% formalin. Plants with the sporogonia mature, but not yet pushed from between the curtains on the under side, can be collected in a tin box which contains damp paper to keep the plants moist. Here the sporogonia will emerge, and by examining them day by day, when some of the sporogonia have emerged, these plants can be quickly transferred to the vials of formalin before the sporogonia have opened and lost their spores. In this condition the plant can be preserved for several years for study of the gross character of the sporogonia and the attachment to the gametophyte. From some of the other plants permanent mounts in glycerine jelly may be made of the spores and elaters.

Riccia.—Riccia occurs on muddy, usually shaded ground. Some species float on the surface of the water. It may be preserved in 2% formalin or 70% alcohol.

Cephalozia, ptilidium, bazzania, jungermannia, frullania, and other foliose liverworts may be found on decaying logs, on the

trunks of trees, in damp situations. They may be preserved in formalin or alcohol. Some of the material may also be dried under pressure.

Mosses are easily found and preserved. Male and female plants for the study of the sexual organs should be preserved in formalin or alcohol. In all these studies whenever possible living material freshly collected should be used.

Ferns.

For the study of the general aspect of the fern plant, polypodium, aspidium, onoclea, or other ferns may be preserved dry after pressure in drying sheets. A portion of the stem with the leaves attached should be collected. These may be mounted on stiff cardboard for use. The sporangia and spores can also be studied from dried material, but for this purpose the ferns should be collected before the spores have been scattered, but soon after the sporangia are mature. But when greenhouses are near it is usually easy to obtain a few leaves of some fern when the sporangia are just mature but not yet open. To prevent them from opening and scattering the spores in the room before the class is ready to use them, immerse the leaves in water until ready to make the mounts; or preserve them in a damp chamber where the air is saturated with moisture.

For study of the prothallia of ferns, spores should be caught in paper bags by placing therein portions of leaves bearing mature sporangia which have not yet opened. They should be kept in a rather dry but cool place for one or two months. Then the spores may be sown on well-drained peat soil in pots, and on bits of crockery strewn over the surface. Keep the pots in a glass-covered case where the air is moist and the light is not strong. If possible a gardener in a conservatory should be consulted, and usually they are very obliging in giving suggestions or even aid in growing the prothallia.

Lycopodium, equisetum, selaginella, isoetes, and other pteridophytes desired may be preserved dry and in 70% alcohol.

Pines.—The ripe cones should be collected before the seeds

scatter, and be preserved dry. Other stages of the development of the female cones should be preserved either in 70% alcohol or in $2\frac{1}{2}$% formalin. The male cones should be collected a short time before the scattering of the pollen, and be preserved either in alcohol or formalin.

Angiosperms.—In the study of the angiosperms, if it is desired to use trillium in the living state for the morphology of the flower before the usual time for the appearance of the flower in the spring, the root-stocks may be collected in the autumn, and be kept bedded in soil in a box where the plants will be subjected to conditions of cold, etc., similar to those under which the plants exist. The box can then be brought into a warm room during February or March, a few weeks before the plants are wanted, when they will appear and blossom. If this is not possible, the entire plant may be pressed and dried for the study of the general appearance and for the leaves, while the flower may be preserved in $2\frac{1}{2}$% formalin, of course preserving a considerable quantity. Other material for the study of the plant families of angiosperms may be preserved dry, and the flowers in formalin, if they cannot be collected during the season while the study is going on.

Demonstrations.—Upon some of the more difficult subjects in any part of the course, especially those requiring sections of the material, demonstrations may be made by the teacher. The extent to which this must be carried will depend on the student's ability to make free-hand sections of the simpler subjects, upon the time which the student has in which to prepare the material for study, and the desirability in each case of giving demostrations on the minuter anatomy, the structure of the sexual organs and other parts, in groups where the material should be killed and prepared according to some methods of precision, now used in modern botanical laboratories. The more difficult demonstrations of this kind should be made by the instructor, and such preparations once made properly can be preserved for future demonstrations. Some of them may be obtained from persons who prepare good slides, but in such cases fancy preparations of

curious structures should not be used, but slides illustrating the essential morphological and developmental features. Directions for the preparation of material in this way cannot be given, in this elementary book, for want of space.

Method of taking notes, etc.—In connection with the practical work the pupil should make careful drawings from the specimens; in most cases good outline drawings, to show form, structure etc., are preferable, but sometimes shading can be used to good advantage. It is suggested that the upper 2/3 of a sheet be used for the drawings, which should be neatly made and lettered, and the lower part of the page be used for the brief descriptions, or names of the parts. The fuller notes and descriptions of the plant, or process, or record of the experiment should be made on another sheet, using one, two, three, or more sheets where necessary. Notes and drawings should be made only on one side of the sheet. The note-sheets and the drawing-sheets for a single study, as a single experiment, should be given the same number, so that they can be bound together in the cover in consecutive order. Each experiment may be thus numbered, and all the experiments on one subject then can be bound in one cover for inspection by the instructor. For example, under protoplasm, spirogyra may be No. 1, mucor No. 2, and so on. In connection with the practical work the book can be used by the student as a reference book; and during study hours the book can be read with the object of arranging and fixing the subject in the mind, in a logical order.

The instructor should see that each student follows some well-planned order in the recording of the experiments, taking notes, and making illustrations. Even though a book be at hand for the student to refer to, giving more or less general or specific directions for carrying on the work, it is a good plan for every teacher to give at the beginning of the period of laboratory work a short talk on the subject for investigation, giving general directions. Even then it will be necessary to give each individual help in the use of instruments, and in making preparations for study, until the work has proceeded for some time, when more general directions usually answer.

APPARATUS AND GLASSWARE.

The necessary apparatus should be carefully planned and be provided for in advance. The microscopes are the most expensive pieces of apparatus, and yet in recent years very good microscopes may be obtained at reasonable rates, and they are necessary in any well-regulated laboratory, even in elementary work.

Microscopes. If the students are provided with microscopes the number will depend on the number of students in the class, and also on the number of sections into which the class can be conveniently divided. In a class of 60 beginning students I have made two sections, about 30 in each section; and 2 students work with one microscope. In this way 15 microscopes answer for the class of 60 students. It is possible, though not so desirable, to work a larger number of students at one microscope. Some can be studying the gross characters of the plant, setting up apparatus, making notes and illustrations, etc., while another is engaged at the microscope with his observations.

The writer does not wish to express a preference for any pattern of microscope. It is desirable, however, to add a little to the price of a microscope and obtain a convenient working outfit. For example, a fairly good stand, two objectives (2/3 and 1/6), one or two oculars, a fine adjustment, and a coarse adjustment by rack and pinion, and finally a revolver, or nosepiece, for the two objectives, so that both can be kept on the microscope in readiness for use without the trouble of removing one and putting on another. Such a microscope, which I have found to be excellent, is Bausch & Lomb's AAB (which they recommend for high schools), costing about $25.00 to $28.00. I have compared it with some foreign patterns, and the cost of these is no less, duty free, for an equivalent outfit. Of course, one can obtain a microscope for $18.00 to $20.00 without some of these accessories, but I believe it is better to have fewer microscopes with these accessories than more without them.

Of the foreign patterns the Leitz (furnished by Wm. Krafft, 411 W. 59th St., N. Y.) and the Reichert are good, while Queen & Co., Philadelphia, Pa., and Bausch & Lomb, Rochester, N. Y., furnish good American instruments.

Glass slips, 3×1 inch; and circle glass covers, thin, 3/4 in. diameter.

Glass tubing of several different sizes, especially some about 5*mm* inside diameter and 7*mm* outside measurement, for root-pressure experiments.

Rubber tubing to fit the glass tubing, and small copper wire to tighten the joints.

Watch glasses, the Syracuse pattern (Bausch & Lomb), are convenient.

U tubes, some about 20*mm* diameter and 10–15*cm* long. Corks to fit.

Small glass pipettes ("medicine droppers") with rubber bulbs.

Wide-mouth bottles with corks to fit. Reagent bottles. (Small ordinary bottles about 10*cm* $\times$ 4*cm* with cork stoppers will answer for the ordinary reagents. The corks can be perforated and a pipette be kept in place in each ready for use. Such bottles should not be used for strong acids.)

A few medium glass cylinders with ground top, and glass plates to cover.

Small vials with corks for keeping the smaller preparations in.

Small glass beakers or tumblers.

A few crockery jars for water cultures.

Fruit jars for storing quantities of plant material.

Glass graduates; 1 graduated to 1000*cc*, 1 graduated to 100*cc*.

Funnels, small and medium (6 and 10 *m* in width). Test tubes. Bell jars, a few tall ones and a few low and broad. Thistle tubes. Chemical thermometer.

Balance for weighing. A small hand-scale furnished by

Eimer & Amend, 205–211 3d Ave., N. Y., is fairly good ($2.00).

Wax tapers or soft-wood splinters.

Glass cylinder, perforated rubber cork for demonstration 27 (see Chapter XVI).

Small porcelain crucibles with covers, and protected wire triangles to support the porcelain dishes while heating.

Apparatus stand, small, several, with clamps for holding test tubes, U tubes, etc.

Agate trays, very shallow, several centimeters long and wide. Agate pans, deep, for use as aquaria, etc., with glass to cover.

Mercury, for manometer in demonstration of respiration.

Sheet rubber, or prepared vessels for enclosing pots to prevent evaporation of water from surface during transpiration experiments.

Litmus paper, blue, kept in a tightly stoppered bottle. Filter paper for use as absorbent paper. Lens paper (fine Japanese paper) for use in cleaning lenses; benzine for first moistening the surface, and as an aid in cleaning.

For materials for culture solution, see Chapter VII.

Reagents.

Glycerine, alcohol of commercial (95%) strength, formalin or formalose of 40% strength, iodine crystals, eosin crystals, fuchsin crystals, potassium iodide, potassium hydrate, potash alum, barium hydrate, caustic potash sticks, vaseline. It is convenient also to have on hand some ammonia, sulphuric acid, nitric acid, and muriatic acid in small quantity.

REAGENTS READY FOR USE AND FOR STORING PLANT MATERIAL IN.

Alcohol. Besides the 95% strength, strengths of 30%, 50%, and 70%, for killing material and bringing it up to 70% for storage.

Formalin. Usually about a $2\frac{1}{2}\%$ is used for storing material, made by taking $97\frac{1}{2}$ parts water in a graduate and filling in $2\frac{1}{2}$ parts of the 40% formalin.

Salt solution 5%; sugar solution 15% (for osmosis).

Iodine solution. Weak—to 300*cc* distilled water add 2 grams iodide of potassium; to this add 1 gram iodine crystals.

Strong—use less water.

Eosin. Alcoholic solution. Distilled water 50*cc*, alcohol 50*cc*, eosin crystals $\frac{1}{5}$ gram, potash alum 4 grams.

Aqueous solution. Distilled water 100*cc*, eosin crystals 1 gram.

STUDENT LIST OF APPARATUS.

One scalpel.

One pair forceps, fine points.

Two dissecting needles (may be made by thrusting with aid of pincers a sewing needle in the end of a small soft pine stick).

Lead-pencils, one medium and one hard.

Note paper; a good paper, about octavo size, smooth, unruled, with two perforations on one side for binding. Several manila covers or folders to contain the paper, perforated also. Enough covers should be provided so that notes and illustrations on different subjects can be kept separate.

REFERENCE BOOKS.

The following books are suggested as suitable ones to have on the reference shelves, largely for the use of the teacher, but several of them can with profit be consulted by the students also. There are a number of other useful reference books in German and French, and also a number of journals, which might be possessed by the more fortunate institutions, but which are too expensive for general use, and they are not listed here.

Kerner and Oliver, Natural History of Plants. 4 vols., 8vo. Henry Holt & Co., New York, 1895.

Strasburger, Noll, Schenck and Schimper, A Text Book of Botany, translated by Porter. The Macmillan Co., New York, 1898.

Vines, Student's Text Book of Botany. The Macmillan Co., New York, 1895.

Atkinson, G. F., Elementary Botany (larger edition). Henry Holt & Co., New York, 1898.

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Where materials cannot be readily collected in the region for class use, they can often be purchased of supply companies.

The Cambridge Botanical Supply Co., Cambridge, Mass., supplies plant material of several groups for study, as well as apparatus and paper.

The Ithaca Botanical Supply Co., Ithaca, N. Y., will supply plants for study in various groups, and upon order will prepare permanent slides for demonstration of the more difficult topics, such as the structure of the sexual organs of liverworts, mosses, ferns, etc.

GLOSSARY OF TERMS USED IN THIS BOOK.

Achene, a dry indehiscent fruit, one-seeded and with the pericarp adherent, 230.

Adherent, term used when one floral set is joined to another, 221, 222.

Ament, a spike which falls away after the maturing of the flower, 227.

Anatropous, said of ovules which are so bent on the stalk that they are inverted, 206.

Andrœcium, the stamens taken collectively, 196.

Antheridium, the male sexual organ, that is, the organ or structure which bears the sperm cells, 122, 141, 142, 171, 173.

Apocarpous, term used when all of the pistils or carpels in the flower are separate from each other, 229.

Apogeotropism, a turning away from the earth, said of stems to indicate the direction of growth with reference to the earth, 108.

Archegonium, the female sexual organ of bryophytes, pteridophytes, and gymnosperms; it contains the egg, 143, 144, 172, 173.

Aril, a secondary outgrowth of the ovular coat in some seeds, 209.

Bracts, small undeveloped leaves, 219.

Bulb, a short underground stem covered with more or less thickened leaves, 219.

Calyx, the sepals taken collectively, 195.

Campylotropous, said of an ovule bent at right angles to its stalk, 206.

Capitulum, a flower head, formed by the close association of several flowers sessile on a shortened axis, 227.

Capsule, a dry fruit with a pericarp which opens at maturity, 230.

Carbohydrate, said of substances containing carbon, hydrogen, and oxygen, the two latter in the proportions in which they exist in water (H_2O), 79.

Carbon dioxide, a compound of carbon and oxygen in the proportion of CO_2, 72, 73, 82, 83, 94–101.

Caryopsis, an indehiscent fruit of one seed and a dry, leathery pericarp, 230.

Catkin, see Ament, 227.

Chalaza, that part of the ovule which is attached to the funicle or stalk, 207, 210.

Chlorophyll, the green pigment in the chlorophyll bodies which gives the green color to leaves, 20, 76, 77.

Chlorophyll body, the proteid body in protoplasm which contains the pigment chlorophyll, 76, 77.

Chloroplast, said of the chlorophyll-bearing body, 77.

Chromoplast, the proteid body in the protoplasm of carrots, and the petals of certain flowers which contains a pigment, 77.

Coherent, said of the members of one floral set when they are united, 221.

Conjugation, a process of fertilization during which the sexual cells become yoked or united, 115, 118.

Corm, a short thick underground fleshy stem, 219.

Corolla, the petals taken collectively, 195.

Cotyledon, the first leaf, or leaves, on the embryo plant, 211–216.

Cyme, said of flower clusters, where the uppermost flower opens first, a determinate inflorescence, 228.

Cymose, a kind of branching present in cymes, 228.

Diadelphous, two brotherhoods, said of stamens when they are grouped or joined in two definite clusters, 270.

Diageotropic, said of stems and leaves which grow in a horizontal direction, 109.

Diageotropism, turning sideways, or parallel with the surface of the earth—term used in reference to stems which grow in a horizontal direction, 108.

Diaheliotropism, term used to denote the direction of growth which stems take when they grow perpendicular to the direction of light rays, 111.

Dichasium, a false dichotomous branching, 228.

Dichotomous, said of an axis where a true forking occurs as the axis branches, 227.

Distinct, said of the members of a floral set when they are separate from each other, 221.

Drupe, a stone fruit with a fleshy pericarp, 230.

Ecology, a study of organisms in their mutual and environmental relations, 283.

Embryo, the young plant in the seed of gymnosperms and angiosperms, 205, 208, 216.

Embryo-sac, the macrospore in angiosperms, the central cavity in the nucellus of the ovule containing the egg, and other nuclei, in which the embryo and the endosperm are formed, 203, 205, 206.

Endocarp, the inner zone of tissue of the pericarp, 229.

Endosperm, the tissue developed in the embryo-sac from the definitive, or endosperm, nucleus after fertilization in angiosperms, 208, 215.

Epigynous, said of flowers where any portion of the calyx or corolla is joined to the ovary, 222, 223, 227.

Exocarp, the outer zone of tissue of the pericarp, 229.

Fertilization, the union of two nuclei, one a sperm nucleus and the other an egg nucleus, 123, 172, 173, 205, 206, 208.

Follicle, a capsule with a single carpel which opens along the ventral or upper suture, 230.

Free, said of floral sets where no one set is joined to another set, 221.

Frond, a nearly obsolete term sometimes applied to the leaves of ferns, but more frequently to the flattened body of certain seaweeds, 217.

Fruit, the mature part of the flower which contains the seed, 228, 230.

Fungi, plants devoid of chlorophyll, possessing mycelium as the structural unit (except certain unicellular forms), 125–138.

Funicle, the stalk of the ovule, 207–210.

Gamopetalous, said of the corolla when the petals are more or less united, 222.

Gamosepalous, said of the calyx when the sepals are more or less united, 222.

Geotropism, term used to express the property of stems and roots when influenced by the earth in direction of growth, 108.

Gynandrous, said of stamens when they are united with the pistil, 243.

Gynœcium, the pistils taken collectively, 197.

Head, same as capitulum, 227.

Heliotropism, a turning influenced by light, said of stems, roots, and leaves when their position is influenced by light, 111.

Hilum, the scar on the seed where it was attached to the wall of the ovary, 207, 210.

Hygrophyte, term used to denote plants which grow in damp situations, and which easily wither when the water supply is checked, 288, 289.

Hypha, a single mycelium thread, 125.

Hypocotyl, the part of the seedling between the cotyledons and the root, 211.

Hypogynous, said of flowers when no floral set is united with the ovary, 222, 223.

Inflorescence, the relation of flowers on an axis or its branches, 225–228.

Insertion, term used in speaking of the position or attachment of the parts of the flower, 221.

Integument, the coat or coats of the ovule, 208.

Irregular, said of flowers where the different members of one or more sets are of different size, 222.

Legume, the fruit of the pea, bean, etc., 230.

Leucoplast, the colorless proteid body in protoplasm of chlorophyll-bearing plants, which under favorable circumstances may become green with chlorophyll, or become a chromoplast, or may act as a centre for the formation of starch grains where starch is stored, as in the potato tuber, etc., 77.

Ligula, the strap-shaped corolla of the flower of certain composites, 278.

Loculicidal, said of capsules which split down the middle line when ripe, 230.

Lodicule, a reduced member of the perianth in grasses, 247, 248.

Macrosporangium, a sporangium which contains the large spores, macrospores, or megaspores, 198, 201.

Macrospores, the large spores which develop only female prothallia, found in certain pteridophytes, in the gymnosperms, and possibly in the angiosperms, 182, 188.

Mesocarp, an intermediate zone of the pericarp, when it is present, 230.

Micropyle, the opening in the free end of the ovule, 209, 210.

Microsomes, term used for the small granules in protoplasm, 25.

Microspores, the small spores in the sporangium in those plants where the spores are differentiated in size as in certain pteridophytes, in the gymnosperms and angiosperms (in the two latter the pollen grains are the microspores), 182, 201.

Monochasium, a kind of branching where one lateral branch is produced from each relative or false axis, 228.

Monopodial, said of the branching of shoots when the main shoot grows more rapidly than the lateral shoots, 227.

Mycelium, the vegetative part of most fungi, 25, 84–89, 125, 131, 134.

Nucellus, the central part of the ovule, 208, 210, 212.

Nucleus, a special organ in protoplasm, of a more dense structure than the remainder of the protoplasm, 21.

Nut, an indehiscent fruit with a dry, hard pericarp, 230.

Oogonium, the female sexual organ of certain low algæ, as vaucheria, and of certain fungi; contains the egg, 122, 123.

Orthotropous, a straight ovule, 206.

Ovule, the macrosporangium of the gymnosperms and angiosperms, 191; occurs usually within or upon the carpel, and at maturity contains the embryo, if that is formed, 191, 198, 201, 205, 206, 207, 210.

Panicle, a raceme with the lateral axes branched, 227.

Pericarp, the part of the fruit which envelops the seed and which forms the wall of the seed, 229, 230.

Perigynous, said of flowers where the stamens or petals are borne on the calyx, 222, 223, 265, 266.

Perisperm, the remnant of the nucellus within the seed, when it is not entirely consumed in the formation of the seed, 208, 210, 212.

Perithecium, the closed or nearly closed fruit body of certain ascomycetous fungi, 136–138.

Phyllotaxy, term used to denote arrangement of leaves on the axis, 11.

Pistil, the member of the flower which contains the ovules, 197, 198, 203, 206.

Pleiochasium, an inflorescence where each relative or false axis produces more than two branches, 228.

Pneumatophore, term applied to special organs of aeration, 327.

Pollination, the passage of the pollen from the stamens to the stigma of the pistil, 192, 205, 241, etc.

Pome, the fruit of the apple, 230.

Poricidal, said of capsules which dehisce by a terminal pore, 230.

Progeotropism, a turning toward the earth, said of roots which grow toward the earth, 108.

Prothallium, the sexual stage of the pteridophytes, gymnosperms, and angiosperms, 166, 170, 203–207.

Protonema, thread-like growth proceeding from the germinating spore of bryophytes, and some pteridophytes, 169.

Protoplasm, the living substance of plants and animals, 15–27.

Pyxidium, pyxis, a capsule which opens with a lid, 230.

Raphe, the part of the stalk of the ovule which is joined to the ovule where the ovule is bent upon its stalk, 207, 210.

Respiration, an interchange of gases by the plant during growth, by which oxygen is consumed and carbon dioxide is liberated, 94–101.

Rhizome, an underground root-stock, 200.

Runners, prostrate stems which take root here and there, 219.

Samara, a winged seed, 256.

Schizocarp, a dry several-loculed fruit in which the carpels separate from each other at maturity but do not dehisce, 230.

Septicidal, applied to a syncarpous capsule in which the carpels separate along the line of their union, 230.

Silique, a capsule of two carpels which separate at maturity, leaving the partition wall persistent, 230.

Spadix, a spike in which the main axis is fleshy, 227.

Spermatozoid, a motile sperm cell, 122, 123, 142, 171, 172.

Sperm cell, the male cell which contains the nucleus for union with the egg nucleus; it may be motile or non-motile, 204, 205.

Spike, an inflorescence with a long main axis, and with sessile flowers on it or on very short lateral axes, 227.

Spikelet, a short lateral flower-branch in the grasses, 247, 249.

Sporangium, a spore case containing spores.

Sporogonium, the entire structure which is the product of the fertilized egg in the bryophytes, 144, 145, 152.

Sporophyll, term applied to leaves in the pteridophytes, gymnosperms, and angiosperms which bear sporangia, 176, 188, 197.

Stamens, the members of the flower which bear the pollen grains or microspores, 201, 203, 206.

Sympodial, said of types of branching where the lateral axes grow more rapidly than the main axis, 227.

Syncarpous, said of the gynœcium when the carpels are united, 229, 230.

Testa, the outer coat of the seed, 208, 210.

Thallophytes, plants of low organization in which the plant body is a frond or thallus, especially the algæ and fungi, 217.

Tropophytes, plants, especially of the North Temperate Zone, which have hygrophytic structures during the summer season, and during the winter season change to xerophytic habit, 288, 289.

Tubers, underground thickened stems, 219.

Umbel, said of an inflorescence where the main axis is shortened and the terminal flowers appear to form terminal clusters, 227.

Xerophytes, plants adapted to grow in dry situations, or in situations where they absorb water with difficulty, 288, 289.

Xylem, the woody elements of the fibrovascular bundle, 64–68.

Zygospore, zygote, a resting spore, formed by the sexual union of two equal or nearly equal cells, 117, 118.

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